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ABSTRACT

The experiments discussed in this report do not have a direct relationship to each other but represent work on a series of sub-issues within the general framework of visual processing of information. Because of this discreteness, the report is organized into a series of papers. The first is a general review of tachistoscopic work on iconic memory and issues related to iconic memory. Following this paper are reports of seven experiments. (Eleven experiments were carried out, but a number of these were follow-up studies and therefore have been incorporated into the discussions of the original experiments.) The topics of the seven experiments are: (1) iconic memory: effects of luminance and cue modality; (2) a developmental experiment on order of report and scanning mechanisms; (3) iconic memory and types of visual cues; (4) iconic memory for letters and geometric forms; (5) binocular and dichoptic cuing in iconic memory; (6) parallel and serial processing in tachistoscopic recognition: two mechanisms; and (7) the role of verbalization in tachistoscopic recognition. (WR)

Final Report

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UTILIZATION AND ORGANIZATION OF VISUALLY PRESENTED INFORMATION

March 15, 1973

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

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Preface

There exist, no doubt, many ways to organize a final report. In the present instance a number of experiments were carried out. The experiments do not bear a direct relation to each other, but rather represent work on a series of sub-issues within the general framework of visual processing of information. Because of this discreteness the report is organized into a series of papers. The first is a general review of tachistoscopic work on iconic memory and issues related to iconic memory. Following this paper are experimental reports of seven experiments. (Actually, eleven experiments were carried out, but a number of these were follow-up studies and therefore have been incorporated into the discussion of the original experiments.) Each of the eight papers is more or less independent of the others.

As with any such project, a number of people have made substantive contributions. For some, their contribution has been recognized by means of authorship of the various papers. In addition, Jeanette Bush, Harry Gray, and Bruce Watson ably assisted particularly with data collection and analysis. The comments of Professors R. N. Haber and D. J. K. Mewhort were also highly useful.

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ICONIC MEMORY AND ITS RELATION TO PERCEPTUAL PROCESSING AND OTHER MEMORY MECHANISMS

A. O. Dick

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The idea of a brief, time-dependent memory serving as an early stage in the analysis of information has existed for a long time (Muller & Pilzecher, 1901, cited in Woodworth & Schlosberg, 1954). Hebb (1949) employed the concept in his two-stage theory of memory. He suggested that memory consisted of a brief neural activity phase (lasting approximately one-half second) and a second permanent, structural trace. In his theory, the function of the activity phase was to maintain the information until the structural cell assembly could be established. Many other investigators have incorporated the two-stage memory concept into their theoretical frameworks. For example, Broadbent (1958) used the concept to explain some of his observations in dichotic listening.

The first clear behavioral evidence in support of such a brief time-dependent memory came in Sperling's (1960) work (c.f. Boynton, 1972). Because accuracy declined with delay of recall, it is assumed that the associated memory trace declines in strength over time, i.e., the memory decays. Sperling's work was soon supported by the results of Averbach and Coriell (1961) and subsequent investigators have generally found support for Sperling's results. Theorizing about Sperling's work came more slowly, but Neisser's (1967) theoretical discussions served to solidify the notion of a rapidly decaying memory.

The theorectical importance of a rapidly decaying memory to more general perceptual issues is clear from the work of Hebb. In addition, there are practical implications of the phenomenon as well. For example, in everyday tasks such as reading, we know that information is primarily taken in during fixations (Erdmann & Dodge, 1898, cited in Woodworth & Schlosberg, 1954; Latour, 1962; Yarbus, 1967). Eye movements are important, of course, in determining the rate of reading and the sequence of fixations. Clearly, however, mechanisms other than eye movements must be involved in making spatial-to-temporal conversions on information taken in during a single fixation. For one approach to the problem see Bryden (1967). Although perceptual events during single fixation have been studied extensively with tachistoscopes since Cattell's (1885) works, only recently have investigators realized that iconic memory is central to most of the research.

The aim of the present paper is to review the perceptual processing literature related to time-dependent memory. Considerable emphasis is given to the partial report tachistoscopic procedure. There is, however, a semantic problem involved in the experiments because many different labels have been used: iconic memory (Niesser, 1967), sensory memory, preperceptual memory, visual short-term memory, visual persistence, etc. The terms are not precise, but all include the idea of a highly labile internal representation. We will use the term iconic memory to refer to this memory (Neisser, 1967) and will also make distinctions between iconic memory, short-term memory (e.g., Miller, 1956) and phenomenal (visual) representation.

A number of issues will be considered throughout the following discussion. First, whether iconic memory is uncoded (as a visual process) or is recorded (as a linguistic process) is an important question, and one that will receive considerable attention. The conclusion reached in this paper is that iconic memory is uncoded but post-retinal. A second related general question is to define the contents and processes of iconic memory. In this context, attention will be also directed toward a methodological problem concerning the cue used to indicate to S which part of the display to report. This aspect of the partial report procedure has received little attention but is critical both theoretically and methodologically as the discussion will attempt to show. The argument will be made that the cue does not affect the icon directly but rather the effect may be indirect by determining the order of transfer into short-term memory. Third, the relation of iconic memory to other mechanisms such as short-term memory will be explicated. In addition to iconic memory, a second visual mechanism will be defined that will be called phenomenal representation. The differentiation between iconic memory and these other mechanisms will first be considered generally in a descriptive model and then will be discussed in detail later.

Discussion on each of the three issues will be distributed through the paper. The organization of the paper follows another more convenient line of questions, namely, those issues that have motivated researchers to carry out various experiments. As an aid to the reader, a descriptive model is shown in Figure 1. In the model, an iconic representation is established as a result of the presentation of a visual stimulus. During the tenure of the icon, the stimulus input is analyzed according to features such as orientation, position, etc. These analyses are assumed to be relatively automatic in the sense that the order of analysis and the type applied to each feature is predetermined.

Upon completion of feature analysis, information is transferred out of iconic memory. The path the information takes depends upon a number of factors, most notably the particular instructions and task given to the subject. For example, the requirement of a verbal response means that the subject will involve short-term memory. The relative amount of involvement, however, will depend upon how many items have to be reported. In general, the greater the number of items to be reported verbally the greater the likelihood that a verbal rehearsal loop will be overloaded. When verbal rehearsal is employed the loop will be loaded by the scanning mechanism which provides a spatial to temporal conversion usually from left to right.

The other path information can follow is into phenomenal representation.

Perhaps a comment is in order about the term. It is borrowed from Attneave and is suggested by some of his research (e.g., Attneave, 1972). The term is more neutral than anything the word "image" or the term short-term visual memory might imply. In spite of the attempt to remain neutral, the reader might wish to substitute one of the other terms and may not noticeably distort the intended meaning. Further, the spatial distinctiveness of phenomenal representation from short-term memory in the figure should not be constructed as indicating systems that operate in an either/or basis. Rather both mechanisms may be operative simultaneously with one being relatively more important than the other depending on the situation and task demands.

There exist a fair number of experimental reports that deal with aspects that could be classified under studies of phenomenal representation (e.g., Brooks, 1968; Scarborough, 1972). Although few of these studies have employed tachistoscopic presentation, some of the data to be reviewed in this paper seem to be consistent with this view.

Both phenomenal representation and short-term memory are assumed to be connected with long-term memory. However, no discussion will be provided to justify this assumption. Similarly, the interplay between phenomenal representation and short-term memory will not receive any attention.

Properties of the Icon

Effects of Stimulus Variables

One relatively obvious and convenient way to study both the contents of iconic memory and the state of coding within iconic memory involves manipulation of physical variables such as stimulus duration and background luminance. Simultaneously, such manipulations may also provide some hints about the locus of iconic memory. As Neisser (1967) notes, if iconic memory is sensory-like rather than cognitive-like, manipulations of exposure duration and luminance ought to have an influence on its duration. Although Neisser reached the conclusion that stimulus variables have an effect on the icon, he had little evidence, and it will be argued here that the evidence that Neisser cited contains methodological problems which allow the data to be interpreted in several ways. The issue can be illustrated in the experiments by Sperling (1960). He reported that the duration of the icon was as long as five seconds if the post-exposure field was dark, but that it was about one-quarter of a second if the following field was lighted. Mackworth (1963) reported an analogous effect. The use of a dark post-exposure field, however, does not allow a straightforward interpretation. For example, a dark post-exposure field introduces both changes in the state of adaptation (Bartlett, 1965) and the increased possibility of confounding after-images. Experiments in which the pre- and post-exposure fields are of the same luminance as the exposure field indicate that the effects of background luminance on the icon are relatively small.

Background Luminance. Since most investigators have used black forms on white background, the luminance reported actually refers to the background. Energy manipulations in tachistoscopic experiments involve changes in the amount of light at the eye but such manipulations seldom involve a change in the contrast ratio because both the targets and background reflect a constant percentage of incident light. Furthermore, the precise specification of luminance levels is exceedingly difficult, such that the reported values may be incorrect by as much as 50%.

Keele and Chase (1967) reported that accuracy in a partial report paradigm varied as a function of the luminance of the stimulus. Furthermore, the rate of decay varied with luminance level and interacted with delay of the cue. Subjects in their experiment were dark-adapted, however, and the interval between the termination of the stimulus and the initiation of the visual indicator was also dark. The luminance levels used were 3.7, 16, and 70 ft-L. The use of a dark pre- and post-exposure field may account for the results, because it is likely that subjects were benefiting from a retinal afterimage. It is known that the brightness of an afterimage is increased with increases in luminance and that the decay characteristics are exponential in time (Brown, 1965).

In another experiment, Eriksen and Rohrbaugh (1970a) controlled the adaptation state of their subjects and reduced the possibility of afterimages by using lighted pre- and post-stimulus fields. They showed letters at either 0.7 or 7.0 ml background luminance. Using a bar marker as a single item cue, they found a small and insignificant effect of luminance on performance. On the average, performance was less than 10 percent better for the higher luminance; and there was no interaction of luminance with delay of the cue. At the same time, the decrease in accuracy due to delay of the cue was on the order of 25 percent for both of the conditions.

Light-adapted subjects were also used in a study of Scharf and Lefton (1970) who measured decay at two luminance levels. The results showed no difference in the decay functions due to luminance. In addition to using light-adapted subjects, their study differed in another way from that of Keele and Chase (1967). Keele and Chase used a visual cue, Scharf and Lefton used an auditory cue. In an attempt to examine possible differences in the cue modality, Lefton and Dick (1973) manipulated background luminance (1.15 and 11.5 ft-L) and used both visual and auditory cues. The results indicate no systematic effect of background luminance or of mode of cueing on either the rate of decay or on the point of asymptote. These results suggest that the mode of cueing does not interact with luminance. Taken together, the data imply that the differential rate of decay obtained by Keele and Chase (1967) can be best accounted for in terms of afterimages. Thus, the available evidence suggests that luminance manipulations do not influence the rate of decay from the icon nor do they have a great influence on performance.

<u>Exposure Duration</u>. The effects of the duration of the stimulus on the integrity of the icon has been investigated by several techniques. Sperling (1960) varied the exposure duration from 15 to 500 msec; the number of letters reported did not vary in either a whole report (immediate memory) or a partial report procedure. The result suggests that much of the energy contained in a long exposure is redundant and not needed. Similar results have been reported by other investigators. For example, Haber and Standing (1969) presented a stimulus repeatedly at a fixed rate and asked subjects to judge whether the brief stimulus appeared perceptually continuous or discontinuous. The apparent duration was independent of the exposure duration of the stimulus over a range of 4 to 200 msec. In addition, the apparent duration did not depend upon whether the stimulus was always presented to one eye or alternated between eyes. In another study (Haber & Standing, 1970), subjects adjusted a click to the apparent initiation of a visual stimulus and another click to its apparent termination. The inter-click interval was used as a measure of the apparent duration of the flash. When flash and adapting field luminances were equal, the apparent duration did not track linearly the physical duration; the post-exposure component of apparent duration decreased as the physical duration increased. The icon could serve to make a short stimulus appear longer but would be unnecessary if the stimulus is of long duration.

Whether one interprets the Haber and Standing (1969; 1970) experiments as suggesting a change in the duration of the icon or not depends upon the theoretical and methodological stance one takes. One could imagine two polar theoretical positions: in the first it is assumed that the icon begins when the stimulus is terminated. From this point of view, one might not expect the results obtained by Haber and Standing. The second position is that the icon begins when the stimulus is initiated and runs its course whether the stimulus is present or not. Under this theory, one would not be surprised at the results of Haber and Standing. Part of this question contains a methodological question as to the way one should measure temporal events.[+] Basically, the most consistent interpretation seems to be that some portions of the physical stimulus may be irrelevant. This argument is supported by data which show that performance does not change over a wide range of stimulus durations. (If the physical presence of the stimulus had an effect, performance would increase as duration increased.) This is tantamount to saying that we use only the first few msec of a fixation to take in information for analysis. A number of investigations have supported this contention (Haber & Nathanson, 1969; Mewhort <u>et al</u>., 1969; Pylyshyn, 1965). To acquire more information, we must make a second fixation (Pylyshyn, 19[illegible]), unless the stimulus is subthreshold (Jackson & Dick, 1969). In summary, the data suggest that the effects of duration are relatively unimportant in influencing performance as long as the subject is not allowed to make a second fixation. Those experiments that do suggest the importance of duration and luminance all have possible confounding effects. Experiments in which the confounds are eliminated show little effect of luminance and duration. This argument, of course, applies only to suprathreshold stimuli, but Neisser (1967) made no distinction between threshold and suprathreshold conditions in his discussion of the duration of the icon.

There are a number of experiments in which it has been argued that exposure duration is an effective variable. Since it is argued here that exposure duration has little effect, it is mandatory to consider some of the conflicting data. For example, Mackworth (1963, Exp. I) varied exposure duration and found that the number of digits correctly reported in correct position increased with increases in exposure duration. One problem with her experiment is that the pre- and post-exposure luminances (39 ft-L) were much higher [illegible] isplay (3 ft-L); the luminance difference is likely to pr[illegible] s[illegible]ultaneously both forward and backward flash masking (Eriksen, 1966). In Mackworth's (1963) situation, increasing the duration of the stimulus changed stimulus onset asynchronies and should reduce the effects of both forward and backward masking with the result that performance should increase. Her second experiment provides evidence for this interpretation; with flash masking eliminated, performance showed a much smaller increase over the first 125 msec. Thus, her results can be interpreted in terms of uncontrolled changes in the amount of flash masking and contrast reduction.

The findings that background luminance and duration are not major variables are counter to well established results in psychophysics, i.e. Block's Law. Under this law, time and luminance can be traded off up to some critical duration. Below critical duration, performance is "state" limited but above critical duration it is "process" limited (Garner, 1965). A change in contrast qualifies as a state limitation and should modify the critical duration. Contrast, duration, and luminance are thought to have retinal influences and therefore would influence iconic memory only if iconic memory were retinal. Since most investigators using tachistoscopic recognition procedures have used mesopic or photopic adaptation, the critical duration should be short and hence increased duration will not influence performance by way of increasing energy at the eye. Although some textbooks on perception suggest using duration thresholds (e.g., Bartley,1969) the method should be avoided for two reasons. First, total energy is usually (although not necessarily) confounded. Second, and more importantly, most investigations studying visual information processing are interested in process limitations and not in state limitations and therefore avoid introducing state limitations.

The Locus of Iconic Memory

(Is the Icon an Afterimage?)

A number of results suggest directly and indirectly that iconic memory is not retinal. The indirect evidence derives from the failure of duration exposure and background luminance to have appreciable effects on either the duration or the rate of loss from the icon. A last bit of indirect evidence implicating a cortical locus involves results obtained by cueing through different modalities. Several unpublished experiments in our laboratory using visual and auditory cues to indicate which row to report do not yield any difference in the rate of decay. Further, comparisons available in the literature between visual and tactual single item probes show consistency between experiments (Averbach & Coriell, 1961;

Smith & Ramunas, 1971).

The more direct evidence involves the use of dichoptic procedures. Averbach and Coriell (1961) report that a metacontrast presented to one eye is effective in masking a letter presented to the other eye. Similar findings have been reported for pattern masking but not for flash masking (Schiller, 1965; Turvey, 1973). Further, Haber and Standing (1969) found no change in apparent duration whether they presented a series of flashes to one eye or alternated the flashes between eyes. Finally, in an unpublished experiment (Dick, 1973) we have found no differences in the rate of decay as a function of whether a bar marker and a row of target letters was presented dichoptically or binocularly.

In general, the data show that decay characteristics are not due to retinal afterimages. As we shall see later, the icon does possess some afterimage-like properties but these properties are not due to retinal mechanisms. These aspects all seem to point to a cortical locus which is distinct from but influenced, of course, by retinal modifications of an input.

Effects of the Cue: Some Methodological Points

With few exceptions (e.g., Eriksen & Colgate, 1971; Eriksen & Collins, 1969; Eriksen & Rohrbaugh, 1970b) investigators have ignored the cue as a topic for study in iconic memory. As will be shown, the modality of the cue seems to make little difference, but the information content of the cue is critical. The basic reason for this is that the cue contains information which must be analyzed to determine what part of the display to report. Some types of information require more time for analysis than others; this may apply to analysis of the cue in other situations as well as in iconic experiments. Furthermore, the time for analysis might vary slightly with modality of cueing since conduction time is somewhat shorter in audition than in vision although the data are not clear on this question.

Two different procedures are commonly used. Both involve the presentation of a visual target stimulus followed by either a visual or auditory cue which instructs the subject what to report. Neisser (1967) points out that the procedure involving the auditory cue easily replicates Sperling's (1960) original results (e.g., Dick, 1969). By contrast, the visual cue single item report procedure of Averbach and Coriell (1961) has been somewhat more difficult and relatively tricky.

There are several attempted replications of the visual cue procedure which fail to find any decay (e.g., Mayzner et al., 1964; Eriksen & Steffy, 1964). There are a number of procedural reasons, however, which explain the failure to obtain decay. First, Mayzner et al. (1964) used light adapted subjects but dark intervals between the stimulus and the cue (Mayzner, personal communication). Thus, the adaptation state co-varies with the variable of interest. Second, Eriksen and Steffy (1964) used a limited set of stimulus alternatives (two); when more alternatives are used in their paradigm, decay is obtained (Keele & Chase, 1967). Clearly, one of the necessary conditions to obtain decay is an overload of the

system, i.e. there must be more items than the subject can report from a brief flash. Third, the meaning or information content of the cue has been varied and as a result processing time of the cue has been inadvertantly varied. A fourth problem with the visual cue is that, depending on how it is presented, it may introduce the phenomenon of visual masking or metacontrast. A monotonic decrease in accuracy is expected with a delay of cue but a monotonic increase is expected with delay of a mask. A combination of these two would change both the magnitude of decay and rate of decay (Jacewitz & Lehmann, 1972). Finally, Townsend (1970) has found that with long visual cues (900 msec) no decay is observed and performance is uniformly low. By contrast, with short cues (40 msec) the Averbach and Coriell procedure consistently produces evidence of decay.

Cue Uncertainty. All partial report experiments in which decay has been observed have a common characteristic: there is event uncertainty in the cue, that is, the cue must contain information about how or what to report. Sperling (1960) had carried out a condition in which full report was delayed and found that report was as accurate in that condition as when the subject did not have to delay his report. We have repeated this experiment several times systematically delaying report up to one second. Accuracy remains stable across all delays, a clear confirmation of Sperling's result. The data suggest that temporal uncertainty by itself is unimportant. To measure decay, of course, event uncertainty must be manipulated relative to the exposure.

Input Modality. Typically, the auditory cue procedure involves report of a group of items. One experiment has examined possible differences between visual and auditory cueing (Lefton & Dick, 1973). They used a visual cue to indicate report of a row of items so that the visual procedure was comparable to the auditory procedure in terms of the number of items reported. In this and other unpublished experiments in our laboratory, no differences in the rate of decay have been found purely as a function of the modality of the cue.

Some additional support for this interpretation is provided by Smith and Ramunas (1971) who used vibrotactile cueing to the fingers to indicate one of the six positions to report from a visual display. Their results show that the stimulus position accuracy curves can be best described as W shaped. That is, there was greater accuracy on the ends and in the middle than in the intermediate positions. Similar results had been reported by Averbach and Coriell (1961) and by Merikle, Lowe, and Coltheart (1971) using bar markers as indicators. Although it may be possible that a future experiment will provide differences, all of the data are consistent and would seem to indicate that the modality in which the cue is delivered is not important.

Information Content of the Cue. The information content of the cue and the difficulty of analysis of the cue can make a difference in whether or not the decay is observed. The visual cueing procedure of Averbach and Coriell (1961) is especially suited to varying the type of cue. In their original experiments, Averbach and Coriell (1961) presented

sixteen letters in two rows of eight. After this display, they presented a bar marker at varying delays which indicated to the subject which letter to report of the sixteen. The results are similar to those of Sperling (1960) because accuracy declined as the bar marker was delayed with respect to the exposure. Subsequently, variations on the Averbach and Coriell task have been used. Townsend (1970), for example, presented eight items in a single row and then presented a single letter which either had or had not appeared as one of the original eight stimulus letters. With this recognition task, Townsend found no evidence of a decline in accuracy as the probe letter was delayed. However, she found evidence for decay using the Averbach and Coriell (1961) bar marker procedure in a parallel experiment.

Manipulations of cue delay are always measured with respect to physical initiation of the cue and never with respect to completion of processing of the cue. If a difficult cue is given a slight time advantage over an easy cue, performance should be more similar. Eriksen and his colleagues (Eriksen & Colgate, 1971; Eriksen & Collins, 1969; Eriksen & Rohrbaugh, 1970) have examined this effect. For example, Eriksen and Collins (1969) employed bar marker and semantic position (digit) cues and presented the cue before, simultaneous with, or following the display. An identity probe has been used in other experiments in a similar way (Dick, Loader & Lefton, 1973; Steffy & Eriksen, 1965). In general, the results show that accuracy is highest with pre-exposure cues and declines as the cue occurs later and later with respect to the exposure. Eriksen and Colgate (1971) suggest that the digit cue takes longer to process than the arrow. It is likely that a letter cue (Dick et al., 1973; Townsend, 1970) takes about as long to process as the digit used by Eriksen and Collins (1969). Therefore, a failure to find decay seems to be due to the longer processing of one type of cue over another. The data have the clear implication that whether or not one measures loss of information will depend upon how much time the subject needs to process the cue. If a lengthy time is required to process the cue, the icon may have decayed before cue processing is completed and consequently, no decay would be observed.

In all of the experiments in which the cue was presented at various times before the display, the results indicate that performance is much better than when it follows the display. Furthermore, an arrowhead need not be given as far in advance as a digit; performance can reach the same high level for all three cues if the processing time for the cue is considered. The benefit of the pre-exposure cues cannot be attributed to eye movements because it takes approximately 200-250 msec to execute a voluntary eye movement (Wheeless, Boynton & Cohen, 1966). Generally, asymptotic performance was reached when the cue appeared 200 msec or less before the initiation of the display. For an identity probe (Dick et al., 1973; Steffy & Eriksen, 1965), eye movements are irrelevant since the probe itself contains no spatial information and hence eye movements would not be useful.

Appleby (1972) has examined visual cue processing time directly in a simple discrimination situation as a function of the number of stimulus alternatives and cue dimension. Using reaction time as a measure, he

found that as the number of alternatives increased, the reaction time also increased. More importantly, he also found systematic differences in cue processing time as a function of dimension. Cues that represent one of two colors take about 11 msec longer than cues that represent letter-number category which in turn take about 10 msec longer than cues representing rows. In addition, he has shown that cue processing time is negatively correlated with performance in a partial report task on these dimensions. The important point of these data is that cues representing different dimensions may take different amounts of time for processing. A difference as small as 10 msec could result in a performance difference as large as one item per trial in report (Sperling, 1963) depending on the rate of processing items.

Cue processing time has been shown to be important when the cue is presented visually. In studies in which auditory cues are used, it is unlikely that it takes any longer to determine whether a 1000 Hz means top row or red, but it may take longer before the subject can actually start to perform the operations required by the cue. By the time the cue is utilized, decay could be complete and hence no further declines in accuracy can be measured. For example, cue utilization time is likely to be an important variable in an experiment by Clark (1969) who showed subjects three rows of five colored circles. Auditory cues were used in two experiments; in the first, the cue indicated one of the colors and the subject was to report the location of those circles. In this experiment no decay was observed. Decay was observed in the second experiment in which the cue indicated a row and subjects reported the color of the items in the row. There is, of course, no reason to expect that one order of analysis need be symmetrical with the reverse order. (See also von Wright (1970).)

Types of Information Lost

Some investigators have attempted to determine the types of information that are lost. Determining what information is lost and what is not lost is helpful in determining the contents and properties of iconic memory. The essence of the partial report procedure is that the experimenter tells the subjects about one aspect of the stimulus and the subject tells the experimenter about another. For example, Sperling (1960) found decay when he cued his subjects according to row and asked subjects to identify the items in that row. Research has shown, however, that the use of the partial report procedure does not automatically lead to decay. Dick (1969; 1970) has cued by both row and color and found decay but has not found decay when cueing by letter-number category or for normal vs. mirror image letters (unpublished). Space and color are physical dimensions whereas the letter-number condition clearly involves a learned distinction. Where identity falls in this continuum is somewhat unclear. If identity refers to a verbal name, it is learned, but if it refers to visual identity, then it need not be learned.

Modifications of the visual cue procedure developed by Averbach and Coriell (1961) are especially suited to examine types of information

lost. Steffy and Eriksen (1965) used one of the items from the display as a cue either before or after the display and asked subjects to report the position that item had occupied. They used three hard to label forms combined with a very long (220 msec) exposure. They claim to have found no decay. However, their statistical analyses are difficult to interpret because instead of considering delay as a continuous variable, they broke it into two variables, pre- and post-cueing and delay. Although a replot of the data with delay as a single variable suggests a linear decrease, the data are difficult to evaluate because of the long exposure duration.

A repetition of the Steffy and Eriksen light adapted condition (Dick, et al., 1973) eliminated the problem of the long duration and concentrated only on post-exposure cues. They used three different kinds of cues and four different sets of stimulus materials. These materials were a) letters, b) numbers, c) familiar geometric forms, i.e., squares, circles, etc. and d) unfamiliar geometric forms, each consisting of two straight lines. The cues were arrowheads, digits, or item cues. For the unfamiliar geometric forms, the response was drawn on a template; for the other materials the response was given verbally. The results in this experiment are quite straightforward. A performance difference was observed: accuracy on the unfamiliar geometric forms was lower than on the geometric forms, which was in turn lower than that on letters and numbers, but even the lowest performance was above chance. This result can be interpreted in terms of information load (Spencer, 1971). With respect to delay of the partial-report cue, the arrowhead showed clear decreases in accuracy for all four materials. There was, however, no evidence in any condition for a decline in accuracy for the semantic-position cue or for the identity cue. Accuracy was near the asymptotic level of the arrow cue. The failure to observe decay with the semantic position or identity cues is due to the longer processing time required for these cues than for arrowheads. The precueing data seem to imply that both position and identity information are lost.

An analysis of the errors provides some important hints about the underlying mechanisms and suggest that some identity information is available. One can distinguish three kinds of errors which indicate that the identity of the stimulus is not lost. The first type is an inversion, a response of an item that was shown to the subject but in another position than that requested. The second type, an intrusion, is defined as report of an item not in the display. The third kind of error is an omission: a failure to respond. Surprisingly, the frequency of intrusion and omission errors is low; they occur on 1% to 31% of the trials, depending on the type of cue and type of material. (The higher frequency of these errors occurs with geometric forms.) There is, of course, something of a trade-off between omissions and intrusions depending on how the experiment is carried out. In fact, omissions can be eliminated by using a forced choice procedure and intrusions reduced or eliminated by changes in the size of the potential stimulus set. The inversions, however, remain and constitute the most interesting type of error. Detailed examination shows that the most frequent source of inversions is the position immediately to the left or

to the right of the requested item, and this is true for all three probes and all materials. This suggests that the internal representation of the spatial arrangement of items is less accurate than physical space and perhaps is somewhat more relative.

By contrast, although inversion errors are also found in multiple item report experiments, these errors account for only a small percentage of the total errors. Intrusion errors are more frequent than inversions but the most frequent error is one of omission. Furthermore, in the multi-item report case, if one uses a cueing procedure in which subjects are asked to respond according to dimensions other than spatial, such as letter-number category or red-black, inversions are very infrequent between the levels of a dimension. Clearly then, although the decay characteristics are quite similar between single and multiple item report experiments, the pattern of errors is quite different. One cannot treat inversions in the same way as omissions or intrusions. Indeed, the errors in the single item report case suggest that the subject saw the relevant portion of the display but he is somewhat uncertain as to its precise spatial arrangement. In all of the cases, if the subject makes a mistake it will most likely be adjacent to the one requested. Thus, for visual probes, the data can hardly be interpreted in any way other than to say that the subject has lost exact spatial position but not other aspects of the representation (c.f. Wickelgren & Whitman, 1970). For multiple item report the decline in accuracy is due to both loss of position and loss of items. The difference between single and multiple item situations may be due to mechanisms other than iconic memory. Indeed, it seems consistent to suggest that single item cueing procedure reflects aspects of phenomenal representation but multiple item cueing reflects short-term memory interactions with iconic memory.

Familiarity of the Display

The data on types of information lost suggest that physical aspects such as space and color are lost whereas learned aspects are not. Amount of learning is closely related to familiarity.

The importance of examining familiarity is suggested by the theorizing of Hebb (1949). Iconic memory could be viewed as the transient activity phase in Hebb's early theorizing. From this point of view, increased familiarity would lead to either a longer or more efficient activity phase and consequently one might expect a slower rate of decay or less decay with more familiar materials than with unfamiliar materials. Most experimenters have used letters or occasionally numbers in their stimulus displays. Letters and numbers are already highly familiar so it is quite easy to reduce the familiarity of the display by using less familiar geometric forms (e.g., Dick et al., 1973), but it is also possible to manipulate familiarity of the display by using approximations to English.[5] According to Hebb's theorizing, a manipulation of familiarity should result in different rates of decay, namely, slower rates with more familiar materials. In general, partial report experiments involving familiarity manipulations do not show differential rates of decay.

Mewhort (1967) presented two rows of letters and varied the statistical familiarity of the rows independently of each other. A post-exposure auditory cue indicated to the subject which of the eight item rows to report. Although the experiment was not designed to make it especially sensitive to decay, there were decreases in accuracy for both orders of approximation as the cue was delayed. He reported that there were no interactions involving delay although zero order approximations decreased slightly more than fourth order approximation. In analogous experiments employing a single item probe procedure, several experiments have been carried out on several orders of approximation (Lefton, 1973; Merikie, et al., 1971). In these cases, a small difference in performance due to orders of approximation is found but this difference can be attributed entirely to chance (Mewhort, 1970). Merikle et al. found a 4% difference between first and second orders of approximation and Lefton found 11 and 16% difference between first and fourth orders in comparable experiments. According to Mewhort's calculations the expected difference between first and second should be about 6% and the difference between first and fourth should be about 12%. Thus, almost the entire performance difference due to order of approximation can be attributed to chance in the single item case but this is quite different from the multi-item free recall case (Mewhort, 1967; Miller, Bruner & Postman, 1954). At the same time, Lefton reported an effect of delaying the cue but no interaction of order of approximation with delay. Dick et al. (1973) found a similar effect with a structural familiarity manipulation. Overall, then, there is no evidence to suggest that the rate of decay is influenced by the familiarity of the stimulus. The performance differences sometimes observed, therefore, cannot be due to alterations of iconic memory. Rather, performance differences are due to the way in which items are transferred out of iconic memory. The notion that single item cueing reflects different mechanisms from multiple item cueing is totally in accord with the failure to find familiarity effects on approximations to English for single item cueing. The general point may be generalized to reaction time data. Posner and Mitchell (1967) found no differences between physical matches for Gibson forms and letters, although physical matches benefit from priming (Beller, 1971) and therefore seem to fit a phenomenal representation interpretation.

The Icon and Eye Movements

Many of the data reviewed in prior sections suggest that the function of iconic memory is to maintain an internal representation of the stimulus so that processing may proceed. As such, the icon might be viewed as an artifact of the tachistoscopic procedure since in the natural environment the duration of the stimulus is seldom restricted in duration. From this point of view, the persisting icon would be redundant since the physical energies are available long enough for complete processing. The data on duration of exposure, however, suggest that the physical presence of the stimulus is redundant and that the icon is used. The one experiment in which the availability of the physical stimulus makes a difference on performance is also the case in which it is possible to make two fixations (Pylyshyn, 1965). The saccadic eyemovement between fixations may have several important functions. The first is an acuity effect in which an

eye movement will have the function of moving a portion of the stimulus to a more sensitive area of the retina. Performance should increase because those portions of the stimulus which were in less sensitive areas of the retina on the first fixation are "moved" to more sensitive areas on the second fixation and hence average resolution across the entire stimulus should increase.

There are situations, of course, in which the entire stimulus will fall on the fovea. When this occurs a second fixation will not serve to move the stimulus to more sensitive positions of the retina. It is in this case that a second function of a second fixation is most apparent, that of generating a second icon allowing for a "second look" at the stimulus. The effect of "multiple looks" should be to increase both the clarity of the stimulus and accuracy of reporting it. Whether more accurate perception is due to an improved percept (Haber, 1967; 1969) or a result of Bayesian decision processes (Doherty & Keeley, 1969; 1972) is a question that has not been completely resolved, although early work suggests that clarity is not correlated with accuracy (Glanville & Dallenbach, 1929).

Under most circumstances the effective processing time (iconic duration) is highly correlated with the latency of voluntary eye movements. Both processing time (e.g., Haber & Nathanson, 1969) and eye movement latencies have duration of roughly 250 msec (Wheeless et al., 1966) depending on the stimulating conditions. Thus, processing is normally ended by the time eye movement occurs. Davidson, Fox and Dick (1973) carried out an experiment in which iconic duration and eye movement latencies were, at least partially, separated. The experiment also contains implications about the role of efference (Festinger, Burnham, Ono & Bamber, 1967) as well as implications about whether the icon is afterimage-like (fixed with respect to retinal space) or distal (fixed with respect to physical space).

Conceptually, the Davidson et al. (1973) experiment is simple: a row of five letters is presented, an eye movement induced, and a mask covering a single letter is presented. Practically, however, the experiment is more complicated; because an eye movement has a moderately long latency relative to the effective delay of a mask, it was necessary to initiate the eye movement before the letters were presented. Davidson, et al. did this and also took care that a stimulus was not presented while the eyes were in motion because sensitivity is reduced during eye movements (Latour, 1962). Latencies of eye movements were recorded to insure that the eyes did not move before the stimulus occurred and also to insure that latencies were not so long that the mask would have no effect. It was shown in a control condition without eye movements that a single letter mask had a relatively local effect, i.e., a mask in the fourth position in the display masked the fourth letter. If the icon is fixed with respect to distal space, the occurrence of an eye movement between the stimulus and the mask should not change the local effectiveness of the mask, that is, it would still mask the fourth letter. If, however, the icon were fixed with respect to retinal space, an eye movement would serve to displace the stimulus such that the mask should not be effective in the same position that it was

under conditions of no movement. Of course, during the experiment, all positions of the display were tested, not just the fourth position. The results suggest that an eye movement moves the icon such that if the mask physically occurred in the fourth position, it actually masked some other letter. Masking was less effective as though sensitivity to the mask was reduced for a brief period after the movement. In addition to naming the letters in the display, the subjects were also asked to identify the position of the mask. Somewhat paradoxically, the subjects almost never missed the true location of the mask. (This is also true for the letters, but no systematic observations were made.) For example, they were able to say that the mask occurred in the fourth position even though it actually affected some other letter. It is possible that efference was used to localize the mask, but a simpler interpretation is that subjects made judgments relative to the fixed edges of the masks in the tachistoscope. This type of judgment probably does not depend on eye movements (Dick & Dick, 1969; Dick, 1972b).

These data suggest that the icon possesses many retinal properties but it is probably not retinal since dichoptic masking can be obtained under similar conditions (Schiller, 1965). The picture emerges that the icon is undoubtedly cortical yet is without benefit of other information such as the eyes have moved. The eye movement information must get integrated somewhat later in analysis. The data show that an eye movement does not "erase" the icon; however, the Davidson et al. (1973) experiment involved a "trick" since the letters were presented near the end of fixation rather than the more typical presentation at the beginning of a fixation. In general, these data are consistent with the interpretation that the iconic representation is the basis of processing, not the physical availability of the stimulus.

From about 50 msec before to 100 msec after the start of an eye movement, the sensitivity of the visual system is reduced (Latour, 1972), which may account for the reduced magnitude of masking in the eye movement case. The icon is without benefit of information that the eyes have moved; moreover, the icon seems to be "protected" during an eye movement such that a subsequent stimulus may be suppressed (Matin, Clymer & Matin, 1972). Under normal circumstances, however, the icon has decayed before a voluntary eye movement can occur. Thus, it is doubtful that the icon is directly responsible for making the world appear perceptually continuous. Rather that function may be more appropriately assigned to phenomenal representation.

Function of the Icon in Relation to Other Mechanisms

Up to this point we have examined issues related to the properties of iconic memory, its contents and variables that will influence the contents. We turn now to experimental works in which the emphasis is on examining the functional aspects of iconic memory such as how material is transferred out of iconic memory, and how iconic memory interacts with other systems and influences subsequent processing.

The Function of the Cue

In his original experiments, Sperling compared the accuracy on full report with accuracy on partial report. His results indicated that the proportional accuracy for partial report was superior to that for full report when the cue occurred shortly after the display, but there was no difference for these two types of report when the cue was delayed beyond 250 msec. A number of investigators subsequently have used this measure as an indication of selection and as a measure of decay (Clark, 1969; Holding, 1970; Turvey & Kravetz, 1970; von Wright, 1968; 1970).

Selection

One implication of the benefit of partial report is that subjects can utilize iconic memory to help to adjust to the demands of the situation. As long as the iconic representation is available, subjects are not penalized by waiting to find out what subset of items should be processed further. Whether subjects wait for the cue before beginning processing or begin processing immediately and then attempt to modify processing when the cue occurs seems to depend upon some subtle differences in the task (von Wright, 1972).

Benefit of Partial Report. Dick (1971) argued that there are two problems associated with this measure. First, if partial report and full report trials are run separately in the experiment, then partial report will show decay but full report will not. If, however, the full report conditions are randomly mixed with the partial report conditions, then both full report and partial report will show a decrease in accuracy (Dick, 1967). When any cue delay is used, a comparison of partial report with full report should be made only under similar conditions, namely, that full report must be mixed in, since it shows a decline in accuracy with increasing delay. The reason full report decays is probably due to the time required to analyze the cue (Appleby, 1972), time which cannot be used to process the display. Furthermore, there is a second problem involved in this kind of procedure, and it contains, perhaps, a more serious confounding. Under partial report conditions subjects are required to make far fewer responses than they are under full report conditions. It is known that "output interference" strongly influences the accuracy of a response with respect to the position in the response sequence (Tulving & Arbuckle, 1963). The second response in a series is typically less accurate than the first, the third less accurate than the second, the fourth less accurate than the third, and so on. Thus, a simple comparison on accuracy for full and partial report is guaranteed to give partial report the edge, because, on the average, it will have less output interference. Dick (1971) analyzed a number of partial report data in terms of accuracy as a function of response position. In all cases analyzed, full report accuracy was higher than partial report accuracy for comparable response positions. At least for the experimental conditions examined (all involved verbal report), the data do not provide any evidence for any sort of mechanism in which the subject can select some parts of the contents of iconic memory to analyze in preference to other parts. Furthermore, output interference effects were independent of decay.

Other data show that the change in the benefit of partial report over delay is due to task parameters. These data simultaneously provide some hints about underlying mechanisms of perceptual processing. Von Wright (1972) examined the benefit of partial report as a function of both written and verbal report. In addition, he compared conditions in which full and partial report were mixed together versus the two run separately. Von Wright was able to obtain data which replicated both Sperling's (1960) and Dick's (1971) results. The difference between full and partial report was much greater when subjects wrote their responses than when they spoke them. Furthermore, the subjects claimed that they used different strategies for the two modes of report. When writing, subjects claimed that they "visualized" the stimuli but when verbalizing the subjects reported that they did not feel that such visualization was of any help, a phenomenon that Brooks (1968) has studied in some detail. The results taken together with the introspective evidence suggest that the role of the phenomenal representation and the nature of processing change as a function of the task. The data suggest that with verbal report the subject begins processing immediately; with written report processing may be delayed until after the cue arrives.

Subject Bias. In an iconic memory experiment subjects do not perform equally well on all members of the display or equally well between rows for that matter. Adult subjects arrive in the laboratory with highly engrained biases which have accrued from their years of reading experience. In the absence of instructions subjects will report a two row display from left-to-right and top-to-bottom (Dick, 1967). This report bias complicates the examination of decay from iconic memory but does not invalidate the findings of decay. Holding (1971) asked subjects to guess which of the three rows they would be asked ro report before each trial. He separated the data into two categories: those trials on which the subject anticipated correctly and those which he anticipated incorrectly. Holding reported that more decay was found for the incorrect anticipations than for the correct ones. Results consistent with this finding were also reported by Dick (1967). Although Holding interprets his data as evidence against iconic memory, the data are perfectly consonant with the notion that iconic memory has a serial output; the last items out of iconic memory should show greater influence of decay than the initial items (Dick, 1967).

Short-Term Memory Selection. Experiments dealing with the order of report in short-term memory show that subjects can easily order their responses in terms of parts of the list. In one such experiment Posner (1964) presented subjects with auditory lists of eight digits at a rate of presentation of either 30 digits/minute or 96 digits/minute. Subjects were instructed to recall the digits either in the order presented or in a separate condition to recall items 5-8 and then 1-4. The results indicate that the first half recalled show the highest accuracy. The relatively slow rate of presentation in comparison to iconic studies would seem to rule out iconic-like effects on the order of recall of the items. A number of other experiments have shown similar effects when order of recall is manipulated both in tachistoscopic recognition (Bryden, 1960; Bryden et al., 1968; Dick & Mewhort, 1967; Scheerer, 1972; 1973) and in

serial presentation (Howe, 1970, chap. 3; Epstein, 1969; 1970). Although one might argue that auditory presentation as used in Posner's study might have different temporal properties from vision, unpublished work from our laboratory using visual presentation confirms Posenr's finding. Taken together, the data suggest that it is unlikely that all characteristics of report accuracy are due to the kinds of analyses that occur in iconic memory. Rather it seems that the analysis is stable and fixed, at least up to the point that items are transferred out of iconic memory.

Processing Interference

The data on selection are consistent with the notion that the cue does not affect the icon directly. Cueing is, of course, only one of the ways that iconic memory has been studied; a second method involves masking. Several types of masking effects occur. For example, in a multi-item tachistoscope display, accuracy is not consistent across the display; items on the end or extreme positions are generally reported more accurately than items in more central positions. Woodworth (1938) suggested that the phenomenon was due to "spatial masking" created by the adjacent letters. This type of explanation has been employed by subsequent investigators even though it has never been clear what sort of interference is involved or whether this interference actually involves masking. However, one implication of this effect is that the underlying mechanism must consist of parallel processes which are relatively independent of acuity factors (Harcum, 1964) and probably are not due to metacontrast (Townsend, Taylor & Brown, 1971; cf. Haber & Standing, 1969b).

In contrast to the data which suggest parallel processes, all of the data which show a rapid decline in accuracy as a function of delay of a cue can be interpreted as involving a serial mechanism (Clark, 1969). That is, if all of the items were processed simultaneously there would be no effect of delaying a cue unless the subject delayed processing until the cue occurred. It is unlikely that the subject delays processing, however, since delayed partial report does not decline to zero performance and different rates of decay are observed for different rows (Dick, 1967). Thus, both parallel and serial mechanisms must be involved in processing.

Two experiments (Dick, 1972a) were designed to examine the relation of two factors to accuracy: a) visual interference (spatial masking); and b) decay of information. A three-row display consisting of four letters per row was used. First, if order of processing is a crucial variable, most of the effect should be observed within a single row and less so between rows. Second, if iconic memory factors are involved, then these effects would be observed as a change in accuracy over time. Finally, if spatial masking is involved, then one should be able to demonstrate this through presentation of a masking stimulus at several delays. The effect of a masking stimulus was measured by applying a mask to part of the three-row display and having the subject report either a masked or an unmasked row as indicated to the subject by an auditory cue.

The results provide important evidence for three points, the effect of the amount and delay of masking and the effect of delaying the cue.

In general, if two rows of the display were masked, accuracy of report was higher for the remaining row than if only one row was masked. In turn, masking one row produced higher accuracy than no masking. Increasing the delay of the mask uniformly decreased accuracy for unmasked rows. By and large, the effect of having material available but not required in report was large and consistent in decreasing level of accuracy. With respect to delay of report (or loss of information from iconic memory), there was evidence of reduced accuracy but this effect was not nearly as large as the accuracy reduction due to unmasked rows.

The differential effects of masking unreported rows and delaying the cue suggest two separate mechanisms. The mask seems to be having its effect at a level in which processing of the input is still in a parallel mode. If this were not the case, the unreported material should have no effect on the level of accuracy of the reported material. (See also Mewhort (1967) who found that the familiarity of the unreported row influenced accuracy of the reported row.) The cue, by contrast, provides evidence that processing is serial. If processing were entirely parallel, delaying the cue would have no effect. Thus, the most reasonable explanation of the effects of the cue seems to be in terms of switching attention or changing the order of transfer of groups of items from iconic memory to short-term memory. This explanation is consistent with the finding that partial report is not better than full report (Dick, 1971) and the finding that cue modality makes no difference (Lefton & Dick, 1973). In partial report, it is likely that the subject will begin to transfer the wrong row on some occasions (Holding, 1971); the cue allows him to switch to the correct row (if necessary), but a switch would require time (Broadbent, 1958) or processing capacity (Mewhort, Thio & Birkenmayer, 1971). If a switch is not necessary, the subject would not have to interrupt transfer with the result that decay would not have set in before transfer is complete. This explanation is consistent with the prediction that if the subject can make the switch in advance, performance will be higher; the data from pre-cueing studies (Dick, 1969) tend to support this prediction.

The Relation of Iconic Memory to Central Processing Capacity

Several experiments have examined the relation of iconic memory to short-term memory. In a preliminary experiment, Turvey (1966) asked subjects to retain five letters, five digits or five binary digits while performing a Sperling task involving letters. There was no effect of the material held in memory on performance of the partial report task, but there was an effect in the reverse direction, i.e. the partial report task affected the material held in memory. A much larger percentage of recall errors occurred when letters were held in memory than when digits were held in memory. Iconic memory does not appear to be influenced by subsequent memories (Wickelgren & Whitman, 1970). This interpretation is supported by Spencer (1971) who presented single letters and varied information load by manipulating the number of possible alternatives; processing time was controlled by use of a mask. Spencer showed that performance asymptoted at 125 msec independent of information load. Increasing information load served to reduce accuracy but did so without

changing the shape of the masking functions. These data are consistent with the interpretation that masking operates while the input is still in a parallel mode of the system, but the information load must have its effect after masking.

Doost and Turvey (1971) examined the effect of processing capacity on iconic memory in more detail. They carried out various manipulations of tasks using the partial report paradigm as an intervening task. In one case, the subject was presented with a CCC trigram. Different conditions show little effect on accuracy, according to whether the trigram was recalled by the subject,or whether it was merely present and not required for recall, or whether it was absent, as in the partial report condition alone. The trigram recall condition was uniformly lower in accuracy but not statistically different from the other condition. There was, in all cases, however, a significant decline in accuracy with delay of the cue and on interaction of delay with condition. A second experiment involved a speeded classification task in which subjects were asked to classify a single letter as either a vowel or a consonant. The visual display and the single, which was presented orally, occurred together. The subject responded as fast as he could classifying the single letter, then a post-exposure delay cue occurred, indicating to the subject how to report the visual display. Here, too, the results show no statistical effect of the classification task on accuracy of report although accuracy was also slightly lower than control conditions. In a third experiment, the selection criterion for the partial report task was that of shape instead of spatial location used in the other two experiments. The speeded classification task was again used, and in this case, there is no hint of a difference due to classification or a decline in performance as a function of delay of the report cue as compared to control conditions.

The conclusions reached by Doost and Turvey (1971) are totally consistent with a differentiation between iconic memory and a phenomenal representation. For example, Posner (1967; Posner & Konick, 1966) has examined the effects of processing capacity on short-term retention of location and distance in a visually guided or motor movement task. The retention interval was either 0 or 20 seconds; for the 20 second condition the interval was either rest or filled with a digit classification task. For the blind (kinesthetic only) task, forgetting was unrelated to activity during the 20 sec. retention interval. For the visually guided kinesthetic retention task, retention was related to interpolated activity with the classification task producing more forgetting than occurred with an unfilled retention interval. Posner has suggested that retention of visual information (especially location) requires some central processing capacity because of the effect of the interpolated task. At the same time, however, Posner argues that the retention of this information is visual, not verbal, because the verbal descriptions used by the subjects were not sufficiently precise to yield the accuracy obtained (Posner & Konick, 1966). Posner's data show that visual retention of spatial location involves some processing capacity and there is a hint in the Doost and Turvey data that retention of spatial position is affected by available processing capacity for the longest delay. If one takes the view that iconic memory will be unaffected by processing capacity manipulations but that phenomenal representation will be, then the small effects observed in the Doost and Turvey experiment could be attributed to the intrusion of the second system.

Capacity and Rate of Processing. Doost and Turvey (1971) reached the conclusion that iconic memory is independent of processing capacity although there are hints that spatial position is affected by processing capacity. In two of their experiments, the capacity used by the to-be-remembered item was in terms of maintaining the item and not analyzing it for its content. An experiment by Mewhort (1972) indicates a complex interaction between the time of arrival of the extraneous material and the familiarity of the visual display. Based on previous work (Mewhort et al., 1969), Mewhort assumed that the contents of iconic memory are scanned to be transferred into short-term memory. Since it had been previously shown that familiar materials are scanned more rapidly than unfamiliar materials, the familiar materials ought for a short period of time to take up more space in short-term memory than would unfamiliar materials. At the same time, however, familiar materials can be recoded or chunked to occupy less space. Thus, the amount of short-term memory capacity required for familiar versus unfamiliar materials ought to vary as a function of the time since presentation, that is, the space required by familiar materials ought to decline with passage of time since presentation. Accordingly, he did the following experiment: a row of letters was presented and either immediately or after one second a row of digits was presented. The exposure duration for both types of materials was 100 msec. In addition, the letter sequences were either of familiar fourth-order approximations to English, or unfamiliar zero-order approximations. At the termination of the digit display, the subject was required to report as many of the letters and digits as he could. The results clearly fit the hypothesis of differential utilization of short-term memory capacity. Familiar materials, indeed, require more capacity immediately after presentation and less capacity after one second. As the presentation of the digits was delayed, letter accuracy increased for both fourth-order approximations and zero-order approximations. More importantly, however, the accuracy on numbers showed an interaction. There was a small improvement in digit accuracy as a function of the delay if the preceding items were zero-order approximations. There was a much larger improvement in digit accuracy, however, if the preceding items were fourth-order approximations. Indeed, at the short inter-stimulus interval digit accuracy was slightly lower if the preceding items were fourth-order than it was if the preceding items were zero-order. These data then suggest that short-term memory capacity does play a role in processing visual information, but in a relatively straightforward manner. If all of the short-term memory capacity is used up, there can be no further gain in the absolute amount of information taken from the icon. This does not mean that new items cannot replace old ones, but the amount or number of items will remain relatively constant. Further, the role that short-term memory capacity plays will also be dependent upon the type of material and how fast it can be read out of iconic memory. Finally, time will also be important since recoding seems to take place in short-term memory and requires some amount of time to transpire.

The data on processing capacity provide information on several points. First, processing capacity cannot be considered to be either visual or verbal but is a combination of both, a point that is clear in the data of Brooks (1968) who showed that two simultaneous verbal or two simultaneous visual tasks took longer than one verbal and one visual task. Second,

however capacity may be filled, it does not seem to influence analyses occurring in iconic memory. This interpretation leads to the implication that iconic memory is independent of meaning or familiarity of the stimulus. Failure to find different rates of decay as a function of varying familiarity of the stimulus is consistent with the interpretation. Third, the differentiation of processing capacity into two modalities lends some credance to the notion expressed earlier that verbal report in single item probe experiments and multi-item cue experiments does not necessarily examine identical aspects of the system. Subjects apparently are quite flexible in trading off visual and verbal capacity depending on the processing demands.

"Cognitive Scanning" and Order of Report

The preceding sections on function of the cue and central processing capacity contain hints about the relation of iconic memory to both short-term memory and pheaomenal representation. We turn now to data that seem to be relevant primarily to the path from iconic memory to short-term memory. The basic question involved in this research is how does a subject convert a spatial array into a sequential-verbal response.

Since the early to middle 1950s, the research on this problem has followed two theoretical orientations. One track has been based on laterality mechanisms in which it is assumed that one hemisphere is more specialized for speech and verbal behavior than the other. It is thought that right-handers will generally have speech localized in the left hemisphere. Accordingly for right-handers, linguistically related materials such as letters or words should be more accurately recognized in the right visual field than in the left since the right field is connected with the left hemisphere. Thus, differences in accuracy on tachistoscopically presented letters to either of the two visual fields can be accounted for in this way. (See White (1969) for a review of this work.) The other line of research has followed a different theoretical orientation, namely, cognitive scanning. The point of divergence may be found in Heron's (1957) work. He showed that when materials are presented simultaneously to both visual fields, then the left field is more accurate. (Also in subsequent work, many investigators (e.g., Bryden, 1960; Scheerer, 1972a) have shown that alphabetic materials are better recognized in the left visual field than in the right visual field with bilateral presentation.) Heron attributed these effects to what he called a "cognitive scanning mechanism," that normally proceeds from left to right with alphabetic materials. Thus, with unilateral presentation, the subject may go from the fixation point immediately to the right and scan in the normal order for materials for the right visual field but with material in the left visual field he must first go to the left which is counter to the normal scanning direction. For the bilateral presentation case, it is much more efficient for subjects to begin on the left and proceed across the display from left to right. Whether or not the unilateral presentation can be explained by this mechanism is well beyond the scope of this paper (cf. Bryden, 1966a). What is of concern, however, is the elaboration of the scanning mechanisms under bilateral presentations condition.

Order of Report

With free recall the subject will tend to report the items in a display in a left to right manner (Bryden, 1966b). Thus, it is not terribly surprising that the left side of the display is better than the right side of the display for several possible reasons. One of these explanations could be in terms of output interference in which it is assumed that the act of responding with one item will interfere with the accuracy of the next response to be made. This explanation can be ruled out for letter materials by two separate experiments. In one, Bryden (1960) asked his subjects to report a single row of letters from left to right or from right to left, giving them a post-exposure instruction cue. He found that subjects had much more difficulty in reporting right to left than from left to right, accuracy was lower, the latency of response was longer, and subjects' introspective reports suggested that it was a more difficult task, and order of report scores were lower. (Order of report scores assess the extent to which subjects can follow the instructions by measuring the sequential nature of the responses.) At the same time, Bryden tested subjects with geometric forms. With these forms he found that subjects could report in either direction with approximately equal accuracy and similar order of report scores. From this experiment it would appear that the left side superiority for letters is not due to order of report-output interference artifact. Rather, the effect is due to the experience of the subject with the materials. Indeed, a follow-up experiment (Bryden et al., 1968) confirmed this for numbers. Numbers are almost as familiar as letters but the order of report was much more flexible.

The second experiment examining the left side superiority on letters was carried out by Mewhort and Cornett (1972). They employed, as stimulus materials, two orders of approximations to English, first and fourth order. On half of the trials, the statistical constraints were in the reverse direction. Thus, a four-order approximation sequence such as MOSSIANT was presented normally and on a subsequent trial might have been presented TNAISSOM. Subjects were provided with post-exposure cues and asked to report these materials from left to right or from right to left. The results show that not only were the subjects better at reporting from left to right than from right to left but also that the familiarity of the stimulus sequence was beneficial for right-to-left report only when the statistical constraints were physically organized in left-to-right orientation.

Taken together, the data of Bryden (1960; Bryden et al., 1968) and Mewhort and Cornett (1972) suggest that there is something unique about letters which almost demand the subject to deal with them in a left-to-right manner. This is clearly not a neural bias as would be suggested by laterality difference but rather a functional bias that is most likely due to specific experience with the materials. Letters are generally treated only from left to right whereas numbers are treated both left to right and right to left (Bryden et al., 1968). Thus, it would seem that the underlying mechanism must be biased due to experience. Indeed, a developmental examination of left to right and right to left report with

letters, numbers and geometric forms seems to confirm this hypothesis (Dick, 1973). The bias seems to be well established empirically, but the underlying mechanism is little understood. There are, however, studies in the literature that provide some hints as to how this mechanism might work and some suggestions for further work to examine the scanning mechanism.

Eyemovements

The cognitive scanning theory of Heron involves a prediction about post-exposure eyemovements which would reflect motor overflow from the internalized scanning. Bryden (1961) has provided such preliminary data. He presented subjects with a single row of letters or geometric forms and recorded eyemovements as well as free-recall accuracy. He found that the direction of the post-exposure eyemovement was correlated with the mean locus of recognition. (Mean locus of recognition here refers to the average of the ordinal positions of the items correctly reported.) The observed correlations suggest that an eyemovement to the left is associated with higher accuracy on the left side and an eyemovement to the right is associated with higher accuracy on the right side. Bryden also reported that there was no relation between order of report and direction of eyemovement. This result is somewhat surprising but may likely have been due to a) the small number of observations that were carried out with each of the two materials per subject and b) that free recall was used. The finding that post-exposure movements are correlated with accuracy is completely consistent with the theory of Hebb (1949) in which he suggested that perceptual development is partially dependent upon motor mechanisms. Because iconic memory is uninfluenced by eyemovements (Davidson et al.,1973) the correlation between the accuracy and eyemovement rules out the sole involvement of iconic memory mechanisms.

Other findings also suggest that the scanning mechanism must be a relatively central cognitive mechanism. Scheerer (1972) has repeated the Bryden (1960) experiment with letters and systematically delayed the direction of report cue. He finds that when the cue is given 250 msec in advance, the subjects are clearly better on the side on which they start. The stimulus position curves for left-to-right and right-to-left report are virtually mirror images of one another. For post-exposure cues, the left-to-right bias exists at a delay of one second and continues to develop up to two seconds when the curves are identical. That is, the accuracy by stimulus position for right-to-left report is the same as that for left-to-right report with a left side bias for long delays of the cue. The relatively slow shift to the left-to-right bias might imply that phenomenal representation is involved.

Other Tasks Not Involving Ordered Report

The left-to-right bias found with ordered report (Bryden, 1960; Bryden et al., 1968; Dick, 1973; Mewhort & Cornett, 1972; Scheerer, 1972) has not been found with procedures in which the subject is asked to report just one item. For example, Smith and Ramunas (1971) presented a single

row of letters and asked the subject to report just one of the letters using a tactile post-exposure cue with systematic delays of the cue relative to the stimulus presentation. They find no bias of the left side over the right at any stimulus delay up to 2 seconds. Similar results with shorter delays have been found by Averbach and Coriell (1961), Lefton (1973), Merikle et al. (1971). Mewhort and Cornett (1972) have argued that the processing demands in the single item report task are different from those in the multiple report task. One cannot attribute this difference to partial report tasks in general, however, since it can be shown that one does get a left-to-right bias in the Sperling partial report task in which a number of items must be reported (Dick, 1967). Thus, the left-to-right bias appears only when the subject must report several items. It is not known, however, how many items must be included in the report.

The failure to find a left side superiority with a visual probe is not at all damaging to a scanning theory but rather is helpful in localizing the mechanism. The findings that multiple and single item partial report tasks produce different patterns of errors also is evidence to suggest different kinds of functions involved for the two tasks. Mewhort and Cornett (1972) have already speculated on the differences in processing demands in the two situations. Especially when letters are presented, there is, in all likelihood, some verbal rehearsal taking place (cf. Posner, 1967). Thus, one interpretation of the scanning mechanism is that it serves to load a rehearsal loop (Glanzer & Clark, 1964). Once such a loop is loaded it is difficult to reverse the order within that loop (for example, reporting an auditory digit sequence backwards). The left-to-right bias normally found in tachistoscopic tasks may be due to the way in which subjects normally operate in preparing for a verbal response.

Scheerer's (1972) data would suggest that some time is needed to load rehearsal. Further, Mewhort et al. (1969) have shown that the rate of processing letters depends upon their statistical constraints or familiarity. Thus, it would seem consistent to suggest that the rate at which rehearsal may proceed will differ as a function of familiarity. Other findings are consistent with this interpretation. For example, Bryden (1960) reports much lower accuracy for geometric forms than for letters. Similarly, Dick (1973) and Mewhort and Cornett (1972) have similar findings with familiarity manipulations. It is not known whether performance differences due to familiarity are a result of the loading of a rehearsal loop or the speed of rehearsal.

Summary and Conclusions

Several general issues were raised in the introduction. Two of these involved the issue of how iconic memory was coded and what the contents might be. The answer appears that iconic memory is uncoded and appears to be a kind of sensory memory which decays over time. The data that bear on this issue include the following: 1) manipulations of familiarity apparently do not affect the rate of decay; 2) the contents of short-term memory do not influence the processing in iconic memory; and 3) it is only physical dimensions of the stimulus which are lost, not learned dimensions.

Although iconic memory appears to be a sensory process, it differs from retinal mechanisms in some important ways. For example, given some threshold amount of energy, further manipulations of energy in the form of luminance or duration manipulations do not appear to affect iconic memory. Further, although iconic memory appears to be fixed with respect to retinal space, it is probably cortical in locus as evidenced by both dichoptic cueing and dichoptic masking (Turvey, 1973). Iconic memory research creates the impression that the icon is a relatively inflexible and fixed mechanism that is analogous to a "neural echo." As such, it should probably not be considered a cognitive process.

The relation of iconic memory to other mechanisms is more difficult to ascertain. Two short-term memory mechanisms, one verbal and the other visual, have been suggested to account for the data. The existence of the verbal short-term memory has been well established; however, the existence of the phenomenal representation is somewhat more inferential and certainly should be the target of further research, particularly its potential relation to work on imagery. Although its existence is rather inferential, the postulation of phenomenal representation does serve to make some sense of many of the observations, such as the difference between single and multiple item report of approximations to English. The general situation seems to be that the adult subject has both mechanisms available and will use one or both as the situation warrants.

Many questions about phenomenal representation cannot be answered at the present time. For example, transfer from iconic memory to short-term verbal memory is probably sequential. However, we do not know how information is transferred from iconic memory into phenomenal representation. Further, verbal memory is influenced by familiarity but it is not known whether phenomenal representation is similarly influenced by such manipulations. To the extent that available data are relevant, it probably is not. Many other such questions can and should be raised concerning this second visual mechanism. As well as having theoretical importance, answers to these questions may well have practical implications for somewhat more applied studies in reading.

Alternative Interpretations of Iconic Memory Data. Implicit in the review is the assumption that iconic memory serves as a useful concept. Recently, Holding (1969; 1970; 1972) has questioned whether it is necessary to postulate such a mechanism. The data he presents in favor of his "aniconic" view are the following: 1) a failure to find a benefit of partial report; 2) guessing strategies on the part of the subject which influence the amount of decay obtained; and 3) a failure to find decay with unfamiliar material. In fact, none of these data are at all damaging to the iconic view. Von Wright (1972) has clarified the benefit of partial report issue by showing the specific conditions under which it is obtained. Furthermore, the presence or absence of the benefit of partial report does not bear on the issue of decay (Dick, 1971). With regard to the guessing strategies of the subject, one would expect differences in decay between rows under a serial transfer to short-term memory (Clark, 1969). The longer an item remains in iconic memory before being transferred the more likely it is to decay. Finally, the finding that performance is

low and does not show decay with unfamiliar material can be explained within the iconic memory framework. Using the Sperling paradigm, Dick (1967) also failed to find decay with unfamiliar materials. However, both Holding's and Dick's experiments involved the use of multiple item report. Dick et al. (1973) used the same stimulus materials as Dick (1967) but employed the Averbach and Coriell (1961) procedure of requiring report of a single item. In this case, decay was observed. Clearly, the number of items required in report makes a difference and would do so presumably as a result of information load on the report system. Although Holding's data may be embarrassing to some interpretations of iconic memory, they are not embarrassing to all.

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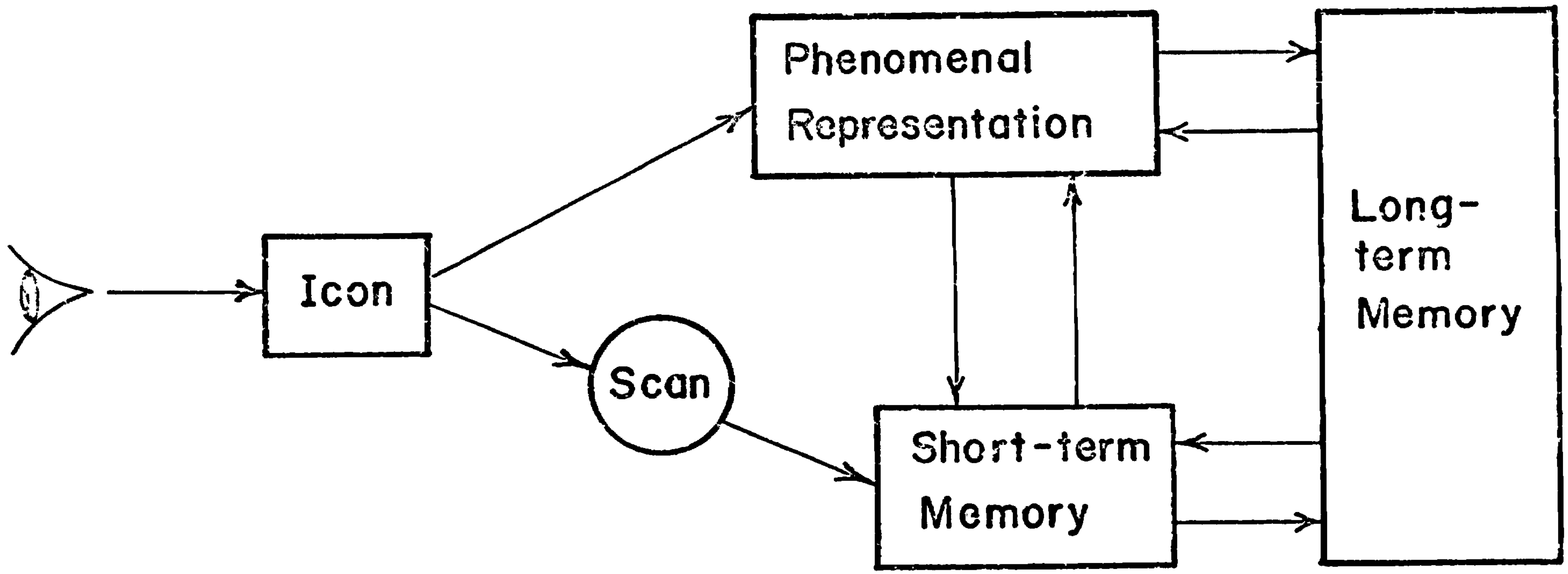
Figure Caption

A schematic diagram representing various components of the visual processing system.


Icon
Scan
Phenomenal Representation
Short-term Memory
Long-term Memory

Iconic Memory: Effects of Luminance and Cue Modality

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Since Sperling's dissertation (1960), considerable evidence has accumulated which substantiates the existence of a brief visual buffer storage. This brief storage has been called by a number of names, among them "persistence" (Haber & Standing, 1969) and more often "iconic memory" (Neisser, 1967). The content of the icon, its duration and decay characteristics have all been investigated (Dick, 1969; Haber & Standing, 1969).

Most studies, however, have ignored the modality of the indicator. Although Sperling (1960) used an auditory cue and Averbach and Coriell (1961) used a visual cue, highly similar results with respect to decay were obtained. Most of the studies which have failed to show evidence of decay have used visual indicators (Mayzner et al. 1964; Townsend, 1970). Studies that have used visual cues as indicators, have usually asked for single items (Averbach & Coriell, 1961), whereas studies that have used coded auditory cues have typically asked S to report a row of letters (Sperling, 1960). Comparisons between these studies are difficult because of differences in output interference and other factors that differ between studies.

One reason for wanting to make such a comparison is that differential rates of decay would suggest that visual and auditory cues operated in different ways. Since the partial report paradigm is thought to examine iconic memory, such a result would force the conclusion that auditory and visual cues examine iconic memory in different ways. The auditory multi-item cue, for example, seems to affect the order of transfer of letters from iconic to short-term memory (Dick, 1972), but it is not clear how the visual single item cue might operate. If there are no differences between visual and auditory cueing on the rate of decay, this result would suggest that the cues operate in roughly the same way regardless of modality and that cues have their effects at a common point.

A second reason for examining cue modality has to do with some hints in the literature that cue modality may interact with the stimulus parameter of luminance. Keele and Chase (1967) employed a visual cue and suggested that background luminance of the display increased the effective duration of the icon. By contrast, Scharf and Lefton (1970) showed little effect of background luminance on performance when an auditory cue was used. The difference in results of these studies could be due to the modality of the cue but the difference is more parsimoniously explained in terms of confounding dark intervals between the stimulus and the cue in the Keele and Chase (1967) study. Therefore, the following study was

undertaken primarily to examine the possible differences of cue modality on rate of decay and, secondarily, to examine the possible interaction of luminance with cue modality.

Method

Subjects. Forty undergraduate students at the University of Rochester served as Ss; participation fulfilled a course requirement. All Ss had normal or corrected to normal vision.

Stimuli. The stimuli consisted of eight different letters in two rows of four. The letters were randomly chosen from an alphabet of 24, (Q and W did not appear). The stimuli were made with black Letraset letters #108, Futura Bold, 20pt/d and overall subtended 1^{o} vertically and 2^{o} horizontally. In the auditory cue condition, a tone was presented of either 400 Hz or 1600 Hz for 500 msec. For the visual cue, two arrowheads appeared in the tachistoscope for 500 msec and flanked the row to be reported. The arrowheads were 18' from the outside of the array and subtended 33' horizontally and 1' vertically at the narrowest point, increasing in height until 17' was reached at the base of the arrow.

Procedure. Twenty Ss were tested with the auditory cues and 20 Ss were tested with the visual cue. Each of these groups was subdivided equally with ten Ss tested with 11.5 Ft-L background luminance level; and ten Ss tested 1.15 Ft-L background.

The stimuli were presented in a three-channel Scientific Prototype tachistoscope (Model GA) for 70 msec. The background luminance of all fields was equated at 11.5 Ft-L. In the low luminance condition, a neutral density filter (1.0 log unit) was placed in front of the eyepiece to reduce the background luminance to 1.15 Ft-L. A fixation point was located between the two rows of letters and midway between items two and three.

After five minutes of dark adaptation, Ss were tested in the following manner. S pressed a switch, the fixation point disappeared and the stimulus appeared for 70 msec.; then, after a variable interval, the cue was presented indicating which row S was to report. The cue came immediately at the termination of the stimulus (0), or 30, 60, 120, or 240 msec. later.

After 15 practice trials, 40 experimental trials were carried out. Since there were ten row report x delay combinations, four randomized blocks of ten trials were arranged. Within each block of ten experimental conditions, there was complete counterbalancing of conditions across stimuli.

Results

The responses were scored in two ways: for the first method, the response had to be in the same relative position that it occupied in the stimulus; for the second method, if a response occurred in any position in the requested row of the stimulus, it was scored as correct. Inasmuch as there were no differences between the two scoring procedures, only the correct in the correct position will be discussed.

The number of letters reported correctly on each trial was entered into an analysis of variance. The main effect of the mode of indicator was found significant ($F(1,38) = 8.27$, $p = .006$) as was the effect of the delay of the cue ($F(4,152) = 6.99$, $p = .001$). Trend analysis applied individually to each mode of indicator showed that linear trends were significant for the auditory mode ($F(1,18) = 17.16$, $p = .000$) and for the visual mode ($F(1,18) = 12.47$, $p = .002$). None of the interactions were found significant. The effect of luminance was not found significant in either mode, visual ($F(1,18) = 1.26$, $p = .276$) or auditory ($F(1,18) = 2.40$, $p = .135$); the data in Figure 1 were therefore collapsed across luminance.

Discussion

One of the main findings of this study is that there were no effects of the different luminance levels on accuracy. To obtain an icon, the stimulus must be above some threshold value (Haber & Standing, 1969). Once this threshold value has been reached, further changes in background luminance seem to have little effect on the extraction of information from iconic storage. These results are in contrast to the results of Keele and Chase (1967) who found significant effects of luminance and a luminance by delay interaction. One possible explanation of their results is that they used a visual cue; however, the results of the present study preclude that interpretation. More likely, their results were obtained because of the use of dark pre- and post-exposure fields. Their stimulus array was exposed for 100 msec. at luminances of 3.7, 16, or 70 Ft-L. With a dark interval preceding and following the array, it is very likely that <u>Ss</u> were not only scanning iconic memory but also their visual afterimages, particularly at the higher luminance level.

The other main finding of this study deals with the mode of indicator used. The type of cue used made a difference in overall performance, the visual cue being somewhat less efficient than the auditory cue. However, the rate of decrease in accuracy does not differ statistically for the two modes of cuing since there is an

insignificant interaction between the mode of cueing and the rate of decay. The failure to find a difference between cue modalities suggests that the cue probably has a relatively central effect and that it probably determines the order of transfer out of iconic memory. (See also Dick (1972).) The finding that auditory cueing leads to better performance than visual may be a rather uninteresting result because it is impossible to equate effectively the strength of the two types of cues.

Neither the background luminance manipulation nor cue modality manipulation affected the rate of loss of iconic information. Both of these outcomes are null hypothesis results and do not, by themselves, constitute strong evidence. Nevertheless, the luminance results are consistent with other experiments in which transcient adaptation has been controlled by using lighted delay intervals (Eriksen & Rohrbaugh, 1970; Scharf & Lefton, 1970). Furthermore, we have carried out other studies manipulating cue modality in which we also find no difference in the rate of decay. Thus, it is unlikely that the failure to find differences is due to insensitivity of the experiment. More likely the differences found in the literature are due to single or multiple item reports which may have different processing demands and possibly different underlying mechanisms (cf. Merikle, Lowe, & Coltheart, 1971; Smith & Ramunas, 1971).

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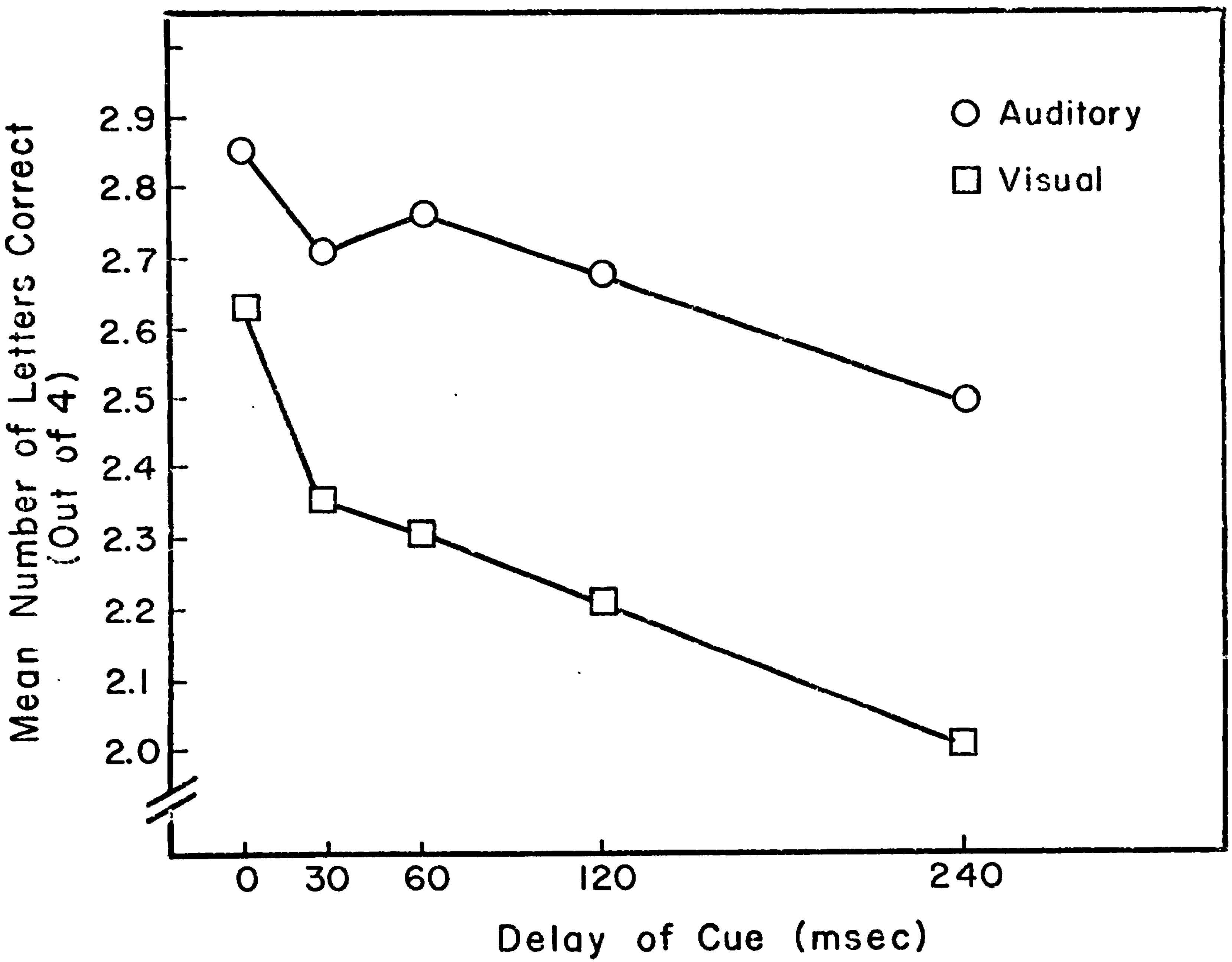
Figure Caption

Figure 1: The mean number of letters reported in correct position as a function of the delay of the cue. The parameter on the curves is the mode of indicator. Each point represents the mean of 80 observations.



Auditory
Visual
Mean Number of Letters Correct
(Out of 4)
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
0
30
60
120
240
Delay of Cue (msec)

A Developmental Experiment on Order of Report and Scanning Mechanisms

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One of the important questions in the processing of information is how the subject converts a briefly presented spatial array into a temporally organized response. What strategies are involved? What sort of long-term functional mechanisms have been developed? What kinds of neural mechanisms are involved?

Since the early 1950s, the research on spatial to temporal conversion has followed two tracks. One track has been to examine laterality mechanisms. It is assumed that one hemisphere is more specialized for speech and verbal behavior than the other. Thus differences in accuracy on tachistoscopically presented letters to either of the two visual fields can be accounted for in this way. It is thought that right-handers will generally have speech localized in the left hemisphere. Accordingly for right-handers, linguistically related materials such as letters or words should be more accurately recognized in the right visual field than in the left since the right field is connected with the left hemisphere. (See White (1969) for a review of this work.)

The other line of research has followed a different path. The point of divergence may be found in Heron (1957). He showed that when materials are presented simultaneously to both visual fields, the left field is more accurate. Heron attributed these effects to what he called a "cognitive scanning mechanism," that normally proceeds from left to right with alphabetic materials. Heron accounted for the unilateral presentation by suggesting that the subject can go from the fixation point immediately to the right and scan in the normal order for materials for the right visual field. However, with material in the left fields, he must first go to the left which is counter to the normal scanning direction, before beginning his scan. For the bilateral presentation case, it is much more efficient for subjects always to begin on the left and proceed across the display from left to right. Whether or not the unilateral presentation can be explained by this mechanism is well beyond the scope of this paper (Bryden, 1966). What is of concern, however, is the elaboration of the scanning mechanisms with bilateral presentations.

Order of Report

With free recall the subject will tend to report the items in a display in a left to right manner. Thus, it is not terribly

surprising that the left side of the display is bette than the right side of the display for several possible reasons. One of these explanations could be in terms of output interference in which it is assumed that the act of responding with one item will interfere with the accuracy of the next response to be made. This explanation can be ruled out for letter materials by two separate experiments. In one, Bryden (1960) asked his subjects to report a single row of letters from left to right or from right to left, giving them a post-exposure instruction cue. He found that subjects had much more difficulty in reporting right to left than from left to right, accuracy was lower, the latency of response was longer, the subjects introspective reports suggested that it was a more difficult task, and order of report scores were lower (order of report scores are a measure of the extent to which subjects can follow the instructions and examine the sequential nature of the responses). At the same time, Bryden tested subjects with geometric forms. With these forms he found that subjects could report in either direction with approximately equal accuracy and similar order of report scores. From this experiment it would appear that the left side's superiority for letters is not due to order of report-output interference artifact. Rather the effect was due to the experience of the subject with the materials. Indeed, a follow up experiment (Bryden <u>et al</u>. 1968) confirmed this for numbers. Numbers are almost as familiar as letters but the order of report was much more flexible.

The second experiment examining the left side superiority on letters was carried out by Mewhort and Cornett (1972). They employed, as stimulus materials, two orders of approximations to English, first and fourth order. On half of the trials, the statistical constraints were in the reverse direction. Thus a fourth-order approximation sequence such as MOSSIANT was presented normally and on a subsequent trial might have been presented TNAISSOM. Subjects were provided with post-exposure cues and asked to report these materials from left to right or from right to left. The results show that not only were the subjects better at reporting from left to right than from right to left but also that the familiarity of the stimulus sequence was beneficial for right-to-left report only when the statistical constraints were organized in left-to-right orientation.

Taken together, the data of Bryden (1960; Bryden <u>et al</u>. 1968) and Mewhort and Cornett (1972) suggest that there is something unique about letters which almost demand the subject deal with them in a left-to-right manner. This is clearly not a neural bias as would be suggested by laterality difference but rather a functional bias that is most likely due to specific experience with the materials. Letters are generally only treated from left to right whereas numbers are treated both left to right and right to left (Bryden <u>et al</u>. 1968). Thus it would seem that the underlying mechanism must be biased due to experience. The bias seems to be well established emperically but the underlying mechanism is little understood.

Failure to Find Scanning

The left-to-right bias found with order of report (Bryden, 1960; Bryden et al. 1968; Mewhort & Cornett, 1972; Scheerer, 1972) has not been found with procedures in which the subject is asked to report just one item. For example, Sm[illegible] and Ramunas (1971) presented a single row of letters and asked the subject to report just one of the letters using a tactile post-exposure cue with systematic delays of the cue relative to the stimulus presentation. They find no bias of the left side over the right at any stimulus delay up to 2 seconds. Similar results with shorter delays have been found by Averbach and Coriell (1961), Lefton (1972), Merikle et al. (1971). Mewhort and Cornett (1972) have argued that the processing demands in the single item report task are different from those in the multiple report task. One cannot attribute this difference to partial report tasks in general, however, since it can be shown that one gets a left-to-right bias in the Sperling partial report task in which a number of items must be reported (Dick, unpublished). Thus the left-to-right bias appears only when the subject must report several items. It is not known, however, how many items must be included in the report.

The failure to find a left side superiority with a visual probe is not at all damaging to a scanning theory but to the contrary is helpful in localizing the mechanism. The findings that multiple and single item partial report tasks produce different kinds of errors also is evidence to suggest different kinds of functions involved for the two tasks. Mewhort and Cornett (1972) have already speculated on the differences in processing demands in the two situations. Especially when letters are presented, there is, in all likelihood, some verbal rehearsal taking place (cf. Posner, 1967). Thus, one interpretation of the scanning mechanism is that it serves to load a rehearsal loop (Glanzer & Clark, 1964). Once such a loop is loaded it is difficult to reverse the order within that loop (for example, reporting an auditory digit sequence backwards). The left-to-right bias normally found in tachistoscopic tasks may be due to the way in which subjects normally operate in preparing for a verbal response.

Scheerer's (1972) data would suggest that some time is needed to load rehearsal. Further, Mewhort et al. (1969) have shown that the rate of processing letters depends upon their statistical constraints or familiarity. Thus, it would seem consistent to suggest that the rate at which rehearsal may proceed will differ as a function of familiarity. Other findings are consistent with this interpretation. For example, Bryden (1960) reports much lower accuracy for geometric forms than for letters. Similarly, Mewhort and Cornett (1972) have similar findings with familiarity manipulations.

The present experiment was conducted to provide information to clarify several problems with existing data and to provide some new data on developmental comparisons. Bryden et al. (1968) compared order of report on numbers with letters and forms. For the letter and form data, however, they used those of Bryden (1960). In both experiments,

the experimenter indicated the direction of report verbally to the subject. Subsequently, Scheerer (1972) has shown that the temporal relation of the cue to the letter display is critical in determining the pattern of performance. Since the Bryden work was separated by several years and done by different experimenters, there is a clear possibility that the difference Bryden et al. (1968) claimed to have found between letters and numbers is simply due to poor experimental design. The present experiment corrected all of the design problems in Bryden's (1960 paper and the problem of comparison of those data with the 1968 data).

The second aspect of the present experiment was to examine developmental changes in order of report. The only data apparently available on development of order of report have been provided by Forgays (1953). Forgays used a unilateral presentation of words and asked subjects of varying ages to report the words. He found an increase in the number of words reported correctly on the right side up to grade 15. Accuracy on the left side increased only up to grade 5. The data indicate the right field superiority does not occur until the seventh grade. The problem with unilateral presentations is, as Heron suggested, that material in the left field require processes that are less than optimal. Scanning efficiency may be increasing steadily but the requirement of counter scanning processes may contraindicate the underlying mechanisms. Therefore, children in fourth and sixth grades were tested with bilateral displays of letters, numbers and forms.

Method

Subjects.--A total of 90 Ss were used in the experiment. Thirty of these were obtained from an introductory psychology class at the University of Rochester for whom participation fulfilled a course requirement. An additional 60 subjects were obtained from the Rochester Public School System--30 sixth grade subjects and 30 fourth grade subjects. All subjects were tested for visual acuity prior to participation in the experiment.

Stimulus Materials.--Three sets of stimulus cards were prepared; one set consisted of letters of the alphabet, a second of numbers, and the third of geometric forms consisting of circles and squares, triangles, stars, crescents, etc. These three sets of cards were prepared using identical rules. The set of stimulus items consisted of ten items for each material; six different items were placed on each stimulus card. The seqences were generated randomly with a restriction that each item appear in each of the six possible positions equally often. This allowed complete counterbalancing with respect to item and position through the set of 80 cards.

The letter and number material was prepared by placing Letraset (Futura Bold, No. 108, capitals) on white cards. The geometric forms were drawn with pen and ink. Template sizes for the forms corresponded to the sizes of the alphanumberic material and were drawn with a Leroy pen (point #4). When viewed in the tachistoscope, all stimulus sequences subtended a visual angle of $3^{o}20' \times 20'$. The width of an individual item was about 16' of visual angle.

Procedure.--The stimulus materials were shown in a Gerbrands two-field tachistoscope. A small black fixation point was provided in one field of the tachistoscope and was present at all times except when the stimulus material was being shown. This fixation point was centered between the third and fourth items and just below the row of stimulus items. In addition, the fixation field contained two small pilot lights with one situated at each end of the stimulus array. These pilot lights were used to indicate to the subject the direction of report he was to follow on that particular trial. The timers of the tachistoscope were used to control the delay between the stimulus exposure and the initiation of the cue light. The delays used from termination of the display to initiation of the cue were 0, 120, 240, 480, and 960 msec. The stimulus materials themselves were shown in the other field for a duration of 50 msecs. The background luminance of the two fields was equated at approximately 4 ftL.

The experiment was carried out on one age group at a time. Within an age, the subjects were randomly divided into one of three groups: One group was shown letter materials; another, numbers and the third, geometric forms. After instruction, each subject received ten trials of practice, one in each of the delay by direction combinations. Following this practice the adult subjects received 140 trials and each of the grade school children received an additional 40 trials. For the developmental comparisons, only the first 40 experimental trials from the adult subjects were used.

Results and Discussion

The data were subjected to a number of analyses. All analyses were consistent with each other, therefore we will summarize the data by discussing just the total correct. Delay of cue was not significant by itself although accuracy according to stimulus position changed with delay; both of these results are in agreement with the data of Scheerer (1972). Accordingly those results will not be discussed. Figure 1 shows the relation of the number of items correctly reported as a function of the material and the side on which report started. Most of the interesting aspects of the data are preserved in the figure.

First it is clear that no age or direction of report differences exist for geometric forms (all F's < 1.0). Age and direction of report differences appear with letters or numbers as stimuli. More items are reported for left-to-right report than for right-to-left report for letters ($F = 32.61$; $df = 1,27$; $p = .0000$) and for numbers ($F = 13.21$, $df = 1,27$; $p = .0002$). The analyses indicate that there are no significant differences for direction of report as a function of age. Implicit in these comparisons is the difference between letters and numbers. As Bryden et al. (1968) indicated, order of report is somewhat more flexible with numbers than with letters.

Some interesting aspects of the data appear when the position an item occupied in the response is correlated with its position in the stimulus. These data are shown in Table 1. These findings show that children are not as good as the adults in keeping track of the position the item occupied in the stimulus. Stated differently, the children are as good as the adults in overall accuracy on the forms but the correlations show that response sequence tends to be more random. Adults not only remember more items, but more importantly, they are better at remembering the positions of the items.

The data also help to clarify one or two issues in the order of report literature, Forgays (1953) argued that right field superiority in unilateral presentations did not appear until the seventh grade. The present data provide a different interpretation of that result. The finding that children do as well as adults on forms but not letters suggests that the speed with which letters can be handled is slower in the children than adults. Haith, Morrison, and Sheingold (1970) showed that five year old children need more time to analyze a form than do adults. Since Haith et al. presented only one form, it is most likely that the difference is due to perceptual factors and not response factors. In this context, the data show that a left-to-right cognitive scanning mechanism exists in children. The speed with which scanning operates, however, increases with experience. Thus, Forgays' (1953) result could be interpreted in terms of speed of scanning and efficiency of perceptual mechanisms without recourse to laterality differences.

A second point of clarification is that the order of report data (Bryden, 1960; Bryden et al. 1968; Scheerer, 1972) are easily reproduced. Therefore, failures to find evidence for scanning are likely to be due to inadvertent changes in task demands. For example, Smith and Ramunas (1971) found no evidence for scanning using a probe (single item report) procedure. It is likely that the probe task creates processing demands different from ordered report tasks (Mewhort & Cornett, 1972).

The present data also contain some implications for investigators who presume to study reading. One obvious point is that use of geometric forms alone will provide no hints about perceptual differences due to reading experience. Geometric forms may be useful in research on adults for simulation of the development of scanning mechanisms. With such materials, one could train subjects to "read" geometric forms and study the integration and organization of materials without taking children's valuable class time.

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TABLE 1

Average Correlation (tau) Between Stimulus

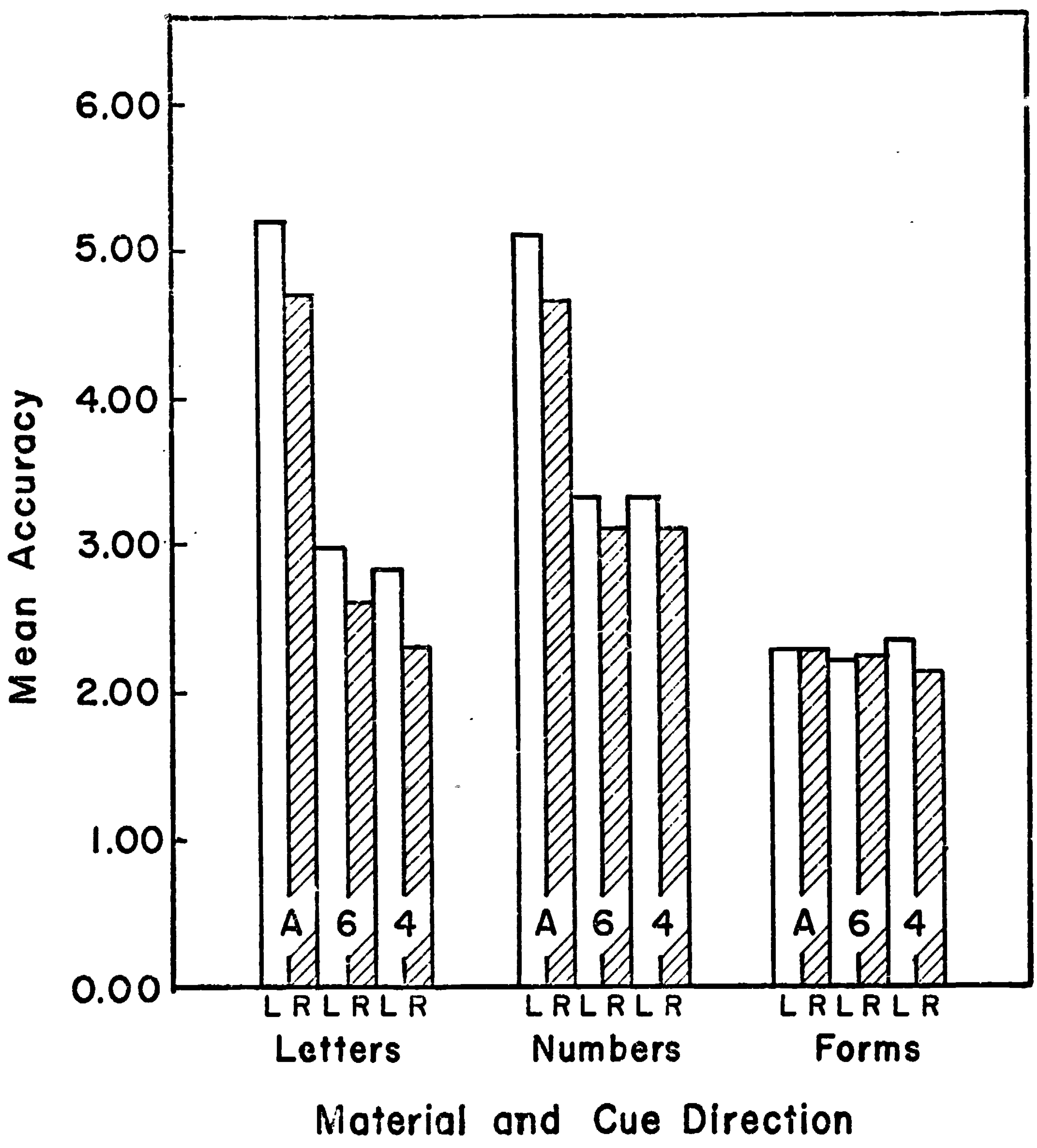
Position and Response Position

Age / Direction of Report	Adults L-R	Adults R-L	Sixth L-R	Sixth R-L	Fourth L-R	Fourth R-L
Letters	.899	-.810	.640	-.507	.652	-.321
Numbers	.826	-.761	.650	-.502	.598	-.484
Forms	.403	-.419	.274	-.111	.339	-.204

Note: The calculations are based on a left-to-right order of report and hence the right-to-left report produces a negative correlation when subjects follow instructions.

Figure Captions

Figure 1. The relation of total accuracy for left-to-right report (open boxes) to right-to-left report (hatched boxes) for each age and each material.



Mean Accuracy
6.00
5.00
4.00
3.00
2.00
1.00
0.00
A
6
4
A
6
4
A
6
4
L R L R L R
L R L R L R
L R L R L R
Letters
Numbers
Forms
Material and Cue Direction

Iconic memory and types of visual cues

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Two cueing procedures are commonly used in the study of iconic memory. In both, a visual display consisting of a number of items, usually letters, is presented. Following this display, a cue is presented to indicate what portion of the display the subject is to report. The basic difference between the two procedures is the type of cue that is used. Many studies have used coded auditory cues following the techniques of Sperling (1960); an alternative procedure is to use a visual cue following the technique of Averbach and Coriell (1961). Both procedures have been used to show that accuracy of report declines over a period of 200-300 milliseconds as the cue is delayed relative to the termination of the stimulus exposure. However, as Neisser (1967, p. 17) points out, Sperling's results are relatively easy to obtain, but the Averbach and Coriell results using a visual cue are more difficult to reproduce.

In the Sperling paradigm, subjects are presented with a visual display consisting of multiple rows of items; the cue indicates to the subject which row of items to report. Due to the nature of auditory signals, most experimenters have limited the number of possible cues to avoid confusion of discrimination on the part of the subject. In some studies, auditory cues have been used to indicate information other than spatial position; in these cases it has not always been possible to obtain a decrease in accuracy (Clark, 1969; Dick, 1969). One interpretation of these results might be that the information conveyed by the cue may be a critical variable in the determination of whether or not decay is observed. A second interpretation might be that some types of information simply do not decay.

This second possibility seems unlikely in light of other experiments. Using visual cues, Steffy and Eriksen (1965) examined decay from iconic memory, but modified their procedure from that of Averbach and Coriell (1961). They presented a display consisting of three unfamiliar forms; these forms were quite difficult as the average exposure of 220 milliseconds indicates. The cue was also one of these forms which indicated to the subject to report the position that form had in the stimulus array. In a dark adapted condition they were unable to find evidence for decay. Indeed, the data suggested that luminance summation was occurring since increased temporal separation of the cue and the stimulus lead to increased performance. For the light adapted condition, there is clear evidence that performance declines as the cue is delayed. Steffy and Eriksen used both pre-and-post exposure cues and there is a consistent difference between the two. As the pre-exposure cue is presented more and more in advance of the display performance increases and as the post-exposure cue is delayed performance decreases. In their analysis this leads to a

significant interaction. If one replots the data, however, so that delay is considered to be both negative and positive, there is a consistent decline in performance as the cue is delayed. This decline is statistically significant, since viewing the data in this way simply converts the interaction to a main effect. Although Steffy and Eriksen did not interpret their data in terms of iconic (pre-perceptual) memory, it is may be consistent to do so.

The finding that difficult to verbalize forms show decay has important implications about the contents and processes of iconic memory. For example, if iconic memory is a pre-linguistic analysis, a manipulation of familiarity should have an effect on the level of performance but not on the rate of decay. By contrast, if iconic memory involves linguistic analyses then there should be no decay with difficult to verbalize forms and performance should be low. Further hints ought to be provided by manipulation of the types of cues used to probe the stimulus presentation. Cues that do not require linguistic analysis should yield performance different from cues that do require such analysis. For example, an arrow that points at one of the positions of the stimulus array probably does not require verbal activity and requires less time than a digit position cue which would force linguistic analysis.

The possibility that different cues require different amounts of time for processing has been examined by Eriksen and Collins (1969). They compared arrow and digit cues and showed that a digit must be presented about 100 milliseconds sooner than an arrow to produce equal accuracy. They concluded that it takes time to process a cue, and that an appropriate time differential must be established if one were trying to equate the effectiveness of two cues.

Taken together, the available data are suggestive but inconclusive with regard to the effects of familiarity and iconic properties. For example, Eriksen and Collins (1969) only used letters; it is known that aspects of visual processing of letter materials differ from those for numbers or geometric forms (Bryden, 1960; Bryden, Dick & Mewhort, 1968). Similarly the data of Steffy and Eriksen (1965) do not allow a differentiation between verbal and non-verbal analyses. The long average exposure duration of 220 milliseconds might be indicative of slow verbal processes; alternatively the subject might be making a physical match between the stimulus items and the cue item (Posner, 1969). Experiment I was designed to examine the effects due to different types of material and the effects of different types of cues. The results indicate that familiarity affects performance but not decay. The data also indicate that the type of cue is important with arrows showing decay but digit and identity cues showing no decay. Experiments II and IIa examined the different cues in more detail with the presentation of some of the cues in advance of the stimulus. In this case both the digit and identity cues showed similar effects of decay, in line with the results of Steffy and Eriksen (1965) as well as Eriksen and Collins (1969).

Experiment I

Method

Subjects. The subjects were 72 undergraduates taking an introductory course in Psychology; participation fulfilled a course requirement. All Ss had normal or corrected to normal vision and were naive to the purpose of the experiment.

Stimulus Materials. Four sets of stimulus cards were prepared; one set consisted of letters of the alphabet, a second of numbers, a third of geometric forms consisting of circles and squares, triangles, stars, crescents, etc. and a fourth a set of nonsense geometric forms each consisting of two lines randomly selected from an alphanumeric Nixie tube display. These four sets of cards were prepared using identical rules. The set of stimulus items consisted of ten items for each material; six different items were placed on each stimulus card. The sequence were generated randomly with a restriction that each item appear in each of the six possible positions equally often. This allowed complete counterbalancing with respect to item and position through the set of 80 cards.

Three sets of cue cards were prepared: one set consisted of arrowheads such that an arrow occurred above and below one of the six items on a card. A second set of cue cards consisted of a digit from 1 to 6 to indicate one of the six items on a card. Finally, a third set of cards was prepared which actually consisted of four subsets, each subset corresponding to one of the types of material used, for example, for letters, the cue cards consisted of a single letter placed on each card. A letter used on a cue card, of course, appeared on the stimulus card.

The letter and number material was prepared by placing Letraset (Futura Bold, No. 108, capitals) on white cards. The two kinds of geometric forms were drawn with pen and ink. Template sizes for the forms corresponded to the sizes of the alphanumeric material and were drawn with a Leroy pen (point #4). Cue cards were made in the same way as the stimulus cards. When viewed in the tachistoscope, all stimulus sequences subtended a visual angle of 3°20' x 20'. The width of an individual item was about 16' of visual angle.

Procedure. The stimuli were shown in a Gerbrands three-channel tachistoscope. The stimulus sequence was the fixation field, stimulus, fixation field for a variable interval, the cue, and then the fixation field again. The cue followed the stimulus at delays of 0,30, 60, 120, 240, 480 milliseconds. The fixation point was centered in the field and fell just below the stimulus item and between positions three and four. The duration of the stimulus and cue were both 50 milliseconds; the background luminance of all three fields was equated at 3.5 ft-L.

The 72 subjects were subdivided into four groups of 18. A single group saw one of the four types of stimulus materials; for example, 18 Ss were presented letters. Each group was further subdivided into three groups of six Ss and was shown one of the three cues.

For each S, the first eight trials constituted practice, followed by 72 experimental trials. Within a group of six Ss, the cue position and delay was counterbalanced across the set of 72 experimental trials, and each position was sampled equally often at each delay, thus allowing for two replications of the 36 stimulus position-delay combinations. For a given S the delays and positions were presented in a random order; these were than counterbalanced across Ss in a group. As a result, each S reported a different item on each card. Furthermore, the particular random orders used for other groups in comparable cueing conditions. For example, a random order was generated for S #1 receiving the letter stimuli; the same random order was used for an S shown the number stimuli.

Where possible, the S responded verbally by either naming the item or naming the spatial position requested. In the case of the nonsense geometric forms, S was provided with a template on which he drew the form requested. The use of a template greatly reduces ambiguity in scoring and did not seem to produce data different from cases in which the S is required to report these by some verbal code.

Results

The individual responses were scored for accuracy and then summed across like conditions. These scores were then subjected to analysis of variance and trend analysis. The results are shown in Fig. 1. The statistical analysis shows clear-cut and consistent effects for all four materials. In each case, monotonically decreasing functions were obtained only for the arrowhead cue ($F(1,5) > 17.25$; $p > 0.01$ for linear). In all of the other cases, the trend components were not significant , i.e., there was no monotonic component. There is one other effect which was quite consistent across the materials, namely, overall performance seems to be fairly closely related to familiarity of the material. Letters and numbers show high performance, the geometric forms are somewhat lower and the nonsense geometric forms are lower still. In summary, the results are straightforward: There is a clear-cut loss for the visual spatial cue, but not for the digit cue nor for the identity. This result could be explained in two ways - a) that only visual spatial information is lost but not other types of information or b) that semantic cues require more time to process than arrows and hence by the time the cue is processed decay is complete. The second alternative is more consistent with the results of Steffy and Eriksen (1965); consequently, it was examined in Experiments II and IIa.

Experiment II and IIa

Method

Subjects. The Ss consisted of 12 undergraduates students taking introductory courses in Psychology and six graduate students in Psychology divided equally among three groups. Eighteen undergraduates were used for IIa. Participation fulfilled a course requirement for the undergraduates. All Ss had normal or corrected to normal vision.

Procedure. The materials and procedure employed in this experiment were identical to those employed in the first experiment. The only difference was that on some occasions the cue appeared before the stimulus appeared. The delay intervals used were as follows. For the precueing cases, the interstimulus interval was 450, 300, 150, 0; for post-exposure it was 0 to 50; for Experiment IIa the intervals were 150, 100, 50, or 0 for advance cues and 0 or 50 for following cues. The two 0 delay conditions in each experiment are in fact separated by the 50 milliseconds stimulus exposure. Again, eight practice and 72 experimental trials were employed. All other aspects, including the randomization orders, were identical with Experiment I.

Results and Discussion

The data obtained in these experiments were treated in analogous way to those in Experiment I, namely, trials were scored for accuracy and like conditions summed. These scores were then entered into analysis of variance. As shown in Fig. 2, both arrowhead conditions show very little evidence for decay ($F(5,25) = 1.29$). By contrast, the digit and identity cue conditions show significant decreases ($F(5,25)=78.63$; $p=.000$). For Experiment IIa digits, $F(5,25)=3.24$; $p=0.022$). Trend analysis showed that the arrowhead curves are flat, but the others are monotonically decreasing functions. This is precisely the kind of result one would expect if different processing times were required on the three types of cues. Thus, there is clear evidence that several kinds of information decay from iconic memory. The reason that it is difficult to measure this effect is because of differential processing times on the various cues. Although the experiments are not sufficiently sensitive to yield a precise estimate of different rates of cue processing, the data are clearly consistent with this interpretation.

The results from these experiments are consistent with other results in the literature. For example, Dick (1969) used auditory cues and a pre- and post-cueing situation. In his spatial condition, there is clearly a possibility that the subject would move his eyes to the appropriate row for pre-exposure cues. However, in some of his other conditions, it is not possible for eye movements to be beneficial. Indeed, in that study he found that presentation of the cue in advance of a display facilitates both color and category report condition. Dick denied the possibility of decay in the pre-cue situation, but such a denial seems to assume that the

cue is analyzed instantaneously. Whether the cue is analyzed instantly or not is not critical if processing time for different cues happens to be equal. The present data indicate that processing times can not be the same for all cues, and indeed identical cues may require different processing times depending on their meaning (Dick, 1969).

General Discussion

The data from Experiment I indicated that familiarity of the stimulus had little effect on determining whether or not decay from iconic memory was observed. The information content of the cue, however, and semantic position cues seem to take longer to analyze and consequently need to be presented sooner to obtain decay. Taken together, these data have implication about the processes of iconic memory.

The finding that decay is not affected by familiarity suggests that iconic memory is pre-verbal. The nonsense geometric forms are difficult to verbalize and show lower accuracy, nevertheless, decay is apparent in the arrowhead condition. The performance differences would seem to be due to a slower rate of transfer for the unfamiliar items. Furthermore, it has been shown with letters, numbers, and familiar geometric forms that order of report differs considerably (Bryden, 1960; Bryden, Dick, & Mewhort, 1968). Order of report becomes less flexible as a directional report cue is delayed (Scheerer, 1972); furthermore, this flexibility decreases as familiarity is increased. The greater number of items to be reported the greater the reliance on short-term memory and the greater the influence of verbal processes and output interference. Since the present data indicate little difference on decay among these materials it is not likely that the order of report effects arise out of iconic memory; instead, they would seem to be due to short-term memory (Posner, 1964). On these grounds single item report experiments are somewhat more likely to be examining "pure" iconic memory than would multiple item report experiments. From these considerations it would seem consistent to suggest that the analyses that occur in iconic memory are independent of verbal familiarity; familiarity effects arise due to changes in rate of transfer for materials of differing familiarity.

The results for the different kinds of cues also provide some hints about the mechanisms involved. The failure to find a difference between the auditory and visual cues (Lefton & Dick , 1972) is consistent with the interpretation that iconic memory is relatively advanced in the system and of cortical locus. Both the tones and the arrows probably do not require semantic analysis. With the digit, and probably the letter, semantic analysis would seem to be necessary and then require some "downstream" projections to iconic memory. The longer (or different) route for analysis of this cue should require more time, which is consistent with the results of Experiment II. This assumes that the verbal system can influence visual memory through image generation (Posner, 1969). Further support for this idea comes from some reaction time experiments of Beller (1971). He used a matching paradigm in which the subject responded 'same' if two letters were physically the same, and 'different' if not.

Beller verbally told the subject about one of the letters in advance on both same and different trials. The advance information served to speed up reaction time on the order of 40 milliseconds for the physical match. Furthermore, the time required for a physical match is not influenced by familiarity (Posner, 1969). Taken together, the data are consistent with the idea of two visual memories the first being iconic and the second a visual short-term memory (Dick, 1973).

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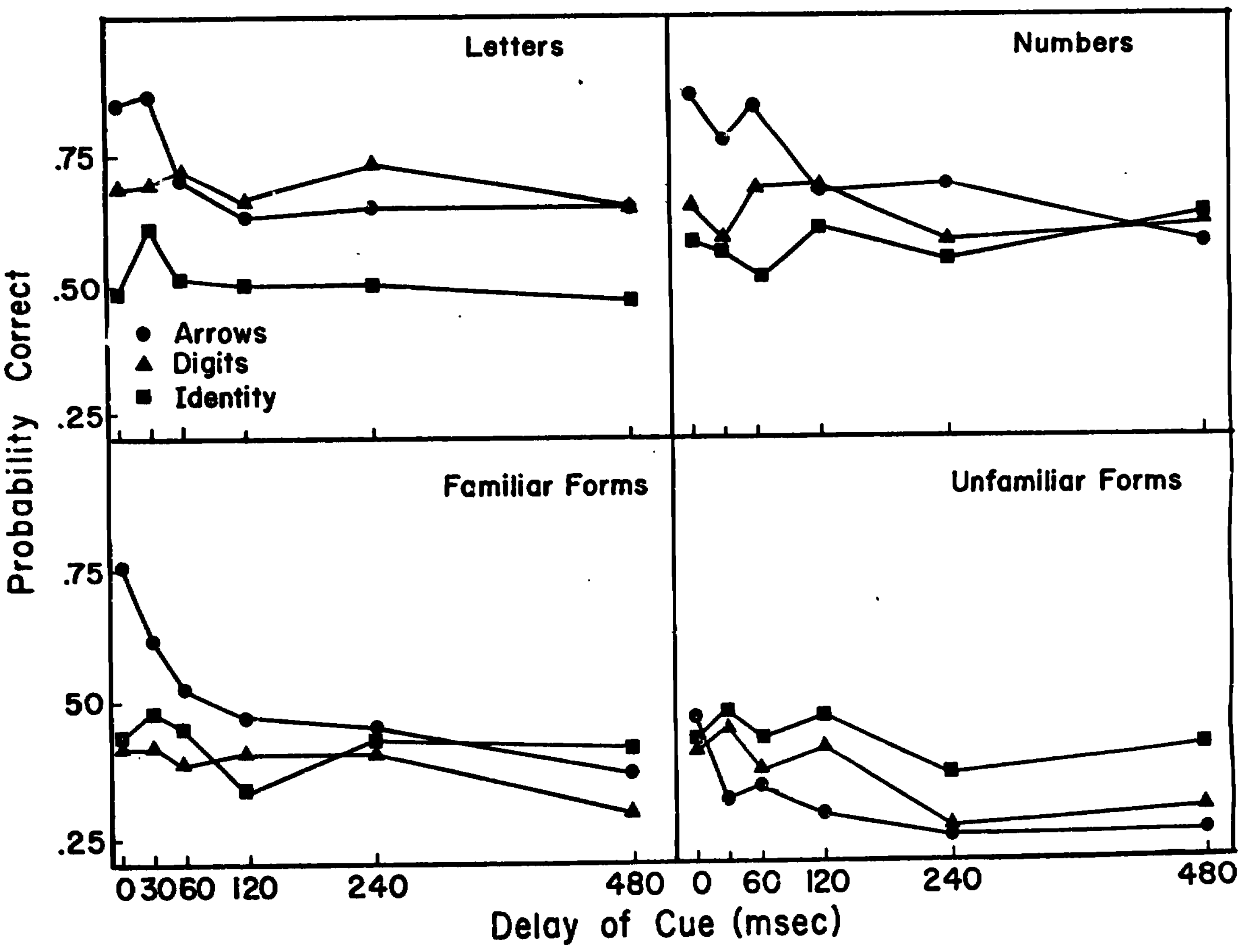
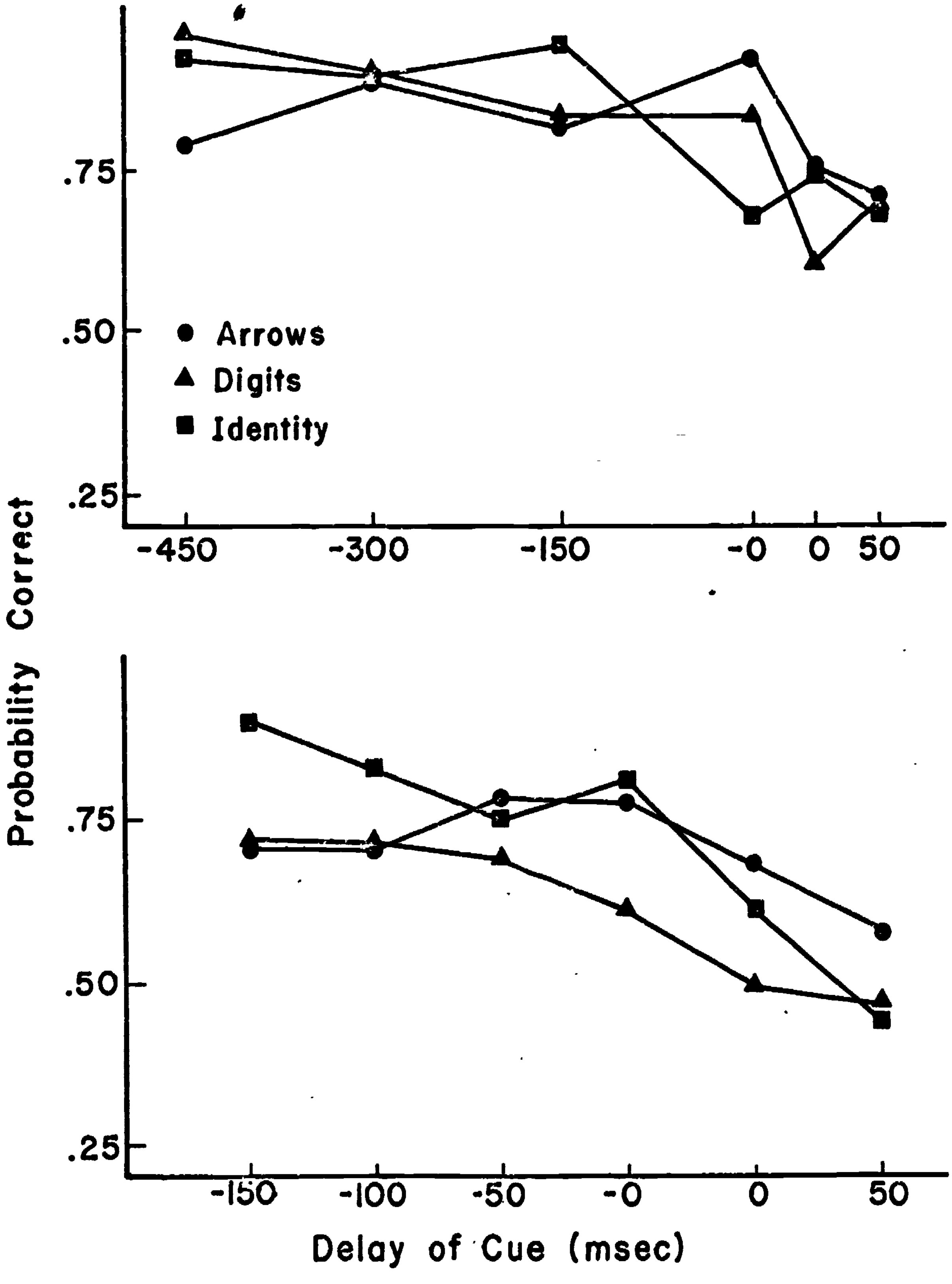
Figure Captions

Figure 1: Accuracy as a function of delay for the three cues (the parameter) and for the four materials (panels).

Figure 2: Letter accuracy as a function of delay of the cues. The delays are interstimulus intervals; positive values indicate post-exposure cueing and negative pre-exposure cues. The stimulus exposure was 50 milliseconds for both Experiment II (Panel A) and Experiment IIa (Panel B).


Letters
Numbers
Familiar Forms
Unfamiliar Forms
Arrows
Digits
Identity
Probability Correct
.75
.50
.25
Delay of Cue (msec)
0 30 60 120 240 480


Arrows
Digits
Identity
Probability Correct
.75
.50
.25
-450
-300
-150
-0
0
50
-150
-100
-50
Delay of Cue (msec)

Iconic Memory for Letters and Geometric Forms

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Many theorists have assumed that the existence of a brief "sensory" memory is a precursor to other forms of memory. The basis of this assumption stems from work by Sperling (1960) and has been substantiated by subsequent investigations using a variety of techniques (Averbach & Coriell, 1961; Clark, 1969; Dick, 1969, 1970; Eriksen & Collins, 1967; Haber & Standing, 1969; Keele & Chase, 1967). Precise specification of sensory memory has not been made, although Neisser (1967) comes closer to a detailed specification than anyone else. Atkinson and Shiffrin (1968), for example, suggest that sensory memory is structural and not influenced by cognitive activity. The impression that Atkinson and Shiffrin (1968) create, as do other discussants, is that the sensory image is virtually a point-for-point representation of a physical stimulus in the cortex. This representation in terms of neural circuitry dissipates as a function of time since removal of the stimulus.

Admittedly, this description is something of an overstatement and no one seems to hold to such a strict view. Furthermore, an old theory (Hebb, 1949) and some recent data do not fit with such a picture. The recent data show that a given stimulus does not always provide evidence of loss of information from this memory. Dick (1969, 1970) presented multidimensional stimuli to groups of _S_s; the groups differed with respect to the dimension to be used in a partial report discrimination. In both experiments, _S_s naming the alphanumeric elements according to spatial position or color showed reductions in accuracy as the report cue was delayed. By contrast, _S_s who were shown the same set of stimuli but asked to report by letter-number category showed no evidence of loss of information. These data suggest that only physical attributes of the stimulus are lost. The very fact that a stimulus does not always show decay raises some questions about sensory memory.

The old theory offers some suggestions about ways to examine sensory memory. In his discussion of memory, Hebb (1949) suggests a continuum with respect to familiarity. The more often an item has been presented, the better its representation in memory. Inasmuch as virtually every study carried out has employed highly familiar, linguistic materials, it is impossible to get any notion of the relation between sensory memory and other forms of memory. A letter is composed of line elements but it is seen as a single unit, that is, it is chunked. A letter simultaneously has a convenient verbal counterpart, a label already stored. These considerations suggest that two avenues of research should be followed: one is to vary the age of the _S_s; the other is to vary the familiarity of the materials. The

former avenue has been explored and is reported elsewhere (Dick, Dick, & Eliot, in preparation). Clear developmental trends were obtained. Using the stimuli of Dick (1969), fourth grade Ss naming items according to color were the only group of that age who showed any decay. By contrast, sixth grade Ss naming items either by spatial location or by color showed loss of information. These results, taken together with other effects obtained, suggest that what is being assessed is not sensory memory at all but rather utilization of memory. The present experiment examines the effect of familiarity of the stimulus. Letters of the alphabet and relatively unfamiliar geometric forms were used in parallel conditions. Coded auditory cues were used in Experiment I; letters decreased in accuracy with delay of cue but forms did not. To explore the possibility that auditory cues may enhance the possibility of linguistic activity and not assess visual activity, Experiment II involved use of visual cues and non-verbal reporting.

METHOD

Experiment I

Subjects. Thirty-two undergraduate students at the University of Waterloo served as subjects (Ss); participation fulfilled a course requirement.

Stimulus materials. Two sets of stimuli were prepared. One set was composed of meaningless geometric forms, the other of letters. There were always eight items on each stimulus card, arranged in two horizontal rows of four. The eight items on a card were selected randomly from the pool of available items; no item appeared twice on the same card.

Form stimuli. Twenty-four different forms were used. Figure 1 shows a composite shape of eight lines, three vertical, three horizontal, and two oblique. Each form incorporated two of these eight lines selected randomly. Any form resembling a letter was not used. The forms were drawn on white cards in India Ink with a Leroy pen, size 3, and a Timely template: each item was ¼" high and 3/16" wide. At a distance of 24", the overall visual angle subtended by the array was 5.0° horizontally and 2.7° vertically. For report of forms, Ss were given a key on which each of the 24 forms were numbered; Ss reported the forms by the number on the key. In addition, Ss were provided with paper and pencil to write down the forms, so that would not have to remember them while searching the key. (Most Ss did not use the pencil and paper.)

Letter stimuli. Twenty-four letters were used; I and W were omitted because of their distinctive size. The stimuli were made with Letraset instant lettering (style #287). The size of each item was ¼" high and approximately 1/8" wide; the overall visual angle subtended by the display was 4.0° horizontally and 2.0° vertically.

Presentation of the materials. The stimuli were presented in a Gerbrands mirror-type tachistoscope. A small black fixation point appeared in Field 1, located such that it fell between the two rows of items and midway between items two and three. The stimulus cards were presented in the other field. Both fields were equated for a background luminance of 3.6 Ft-C. The exposure duration for forms was 100 msec., for letters, 50 msec.

The tachistoscope timers were also used to control an audio oscillator which produced a pure tone to instruct the S how to report. A high pitch tone (1000 Hz) indicated that S should report the top row; a low pitch tone (200 Hz) indicated that S should report the bottom row. The interval from the offset of the visual array to the onset of the tone was varied. Eight different delays were used: -850, -450, -50, 50, 250, 450, 650, and 850 msec.

The order in which the stimulus cards were presented was always the same for a given stimulus material. Each S received 64 trials, four randomized blocks of the 16 delay-instruction conditions. Thus, each S had to report the top row at a delay of 650 msec. four times. To minimize the effects of practice, the order of the delay-row conditions was randomized within each block and then counterbalanced across Ss. Settings on the timer and oscillator were moved on every trial.

Experiment II

This experiment was a replication of Experiment I. The main difference between the two experiments was the mode of indicator; Experiment I used a coded auditory cue, Experiment II used a visual cue. There were some other small changes. They are indicated below.

Subjects. Thirty-two undergraduate students from the University of Rochester served as Ss; participation fulfilled a course requirement.

Stimulus material. The same stimuli were used. Visual angles were slightly different, however, due to a greater viewing distance. At a distance of 29", the overall angle subtended by the letters was 3^{o} 17' horizontally and 1^{o} 47' vertically. The forms subtended 3^{o} 43' horizontally, 2^{o} 13' vertically.

Presentation of the materials. The luminance level of the background of both fields was 4.7 Ft-C; the exposure duration for both forms and letters was 100 msec. Subjects were cued which row to report by small dim lights placed in the fixation field of the tachistoscope. At the offset of the stimulus the fixation field reappeared and at some variable delay, two small lights were additionally illuminated. Four lights were arranged such that two flanked the sides of the top

row, and two flanked the sides of the bottom row. These lights were 1° from the outside of the array. The interval from the termination of the visual array to the initiation of the lights indicating which row to report was varied: eight different delays were used: 0, 30, 60, 120, 250, 450, and 850 msec.

Subjects were given response grids on which they were asked to draw the items in the row indicated. For letters, they wrote the four letters indicated in either the top row of the grid or the bottom row. For forms, the grid was made up of two rows of four drawings as in Figure 1. Subjects were asked to trace over the two lines that made up the forms in the stimulus. A new grid was provided for each trial. Within each S there were four randomized blocks of the 16 delay-row conditions. To minimize the effects of practice, counterbalancing as described in Experiment I was used. In addition, there were eight practice trials before each session.

RESULTS AND DISCUSSION

Analyses of variance were applied to the number of items correctly reported for each trial. Separate analyses were carried out on the material within the two experiments. For Experiment I, the overall effect of delay was highly significant for both forms and letters, but analysis of just the post-exposure intervals showed significant effects of delay only for letters (forms, $F = .592$; letters, $F(4, 601 = 3.895$, $p = .007$). Analysis of the data from Experiment II confirmed the results of Experiment I (for forms, $F = .985$; for letters, $F\ (7, 105) = 5.26$, $p = .0001$). The effects of post-exposure delay for the two experiments are shown in Figures 1 and 2. It is clear from the figures that the mode of cueing had no systematic influence on the rate of decay.

It was possible in Experiment I that decay was not observed for forms due to a) the low accuracy, and b) that decay may have occurred before the 50 msec. delay point. Experiment II shows no systematic effect of delay between 0 and 60 msec. thus discounting the idea of a very rapid decay for forms. This idea is further discounted by the findings of Steffy and Eriksen (1965) who used form stimuli and found decay persisting over 250 msec. or so. Their experiment was quite different in the sense that they presented a form as a cue and asked Ss to report the position of that form in a previous display. Apparently,when letters were used as stimuli in a manner analogous to the Steffy and Eriksen (1965) experiment, there was no decay observed Townsend, 1970).

The present data show virtually no difference on rate of decay due to cue modality and similar failure to note differences was observed by Lefton and Dick (1972). If iconic memory were a visual phenomenon, it is unlikely that visual and auditory cues could operate in the same way.

An auditory cue would have to have some "downstream" effect on visual processing whereas the visual cue would have to have the opposite influence. Inasmuch as mode of cueing makes no difference, it would seem more reasonable to conclude that both cues operate at the same point in the system and this point is not in sensory memory. This interpretation is bolstered by the observations a) that stimulus variables such as luminance are not effective in rate of decay (e.g. Lefton & Dick, 1972), and b) selection apparently does not occur in any visual memory (Dick, 1971; Holding, 1970), and c) that noise masking and cueing are a result of different mechanisms (Dick, 1972).

The results of these experiments are consistent with those of Dick et al. (in preparation) on children. They did not find decay for fourth grade children who were cued spatially. The present data, taken together with other data, suggest that the icon is uninfluenced by stimulus variables such as luminance (Lefton & Dick, 1972) but is influenced strongly by specific experience, particularly that of learning how to use spatial information and perhaps other cognitive mechanisms.

The present experiments further suggest that verbal labels influence perceptual processes. It is known that language affects reproduction of visually perceived forms (Carmichael, Hogan, & Walter, 1932; Herman, Lawless, & Marshall, 1957) and Bruner, Busiek and Minturn (1952) have shown that perceptual assimilation is influenced by verbal labels. Thus, the loss of information from iconic memory may be influenced by verbal labels and by specific experience with the materials. The use of unfamiliar forms may provide an important technique for disassociating linguistic and experiential variables in iconic memory.

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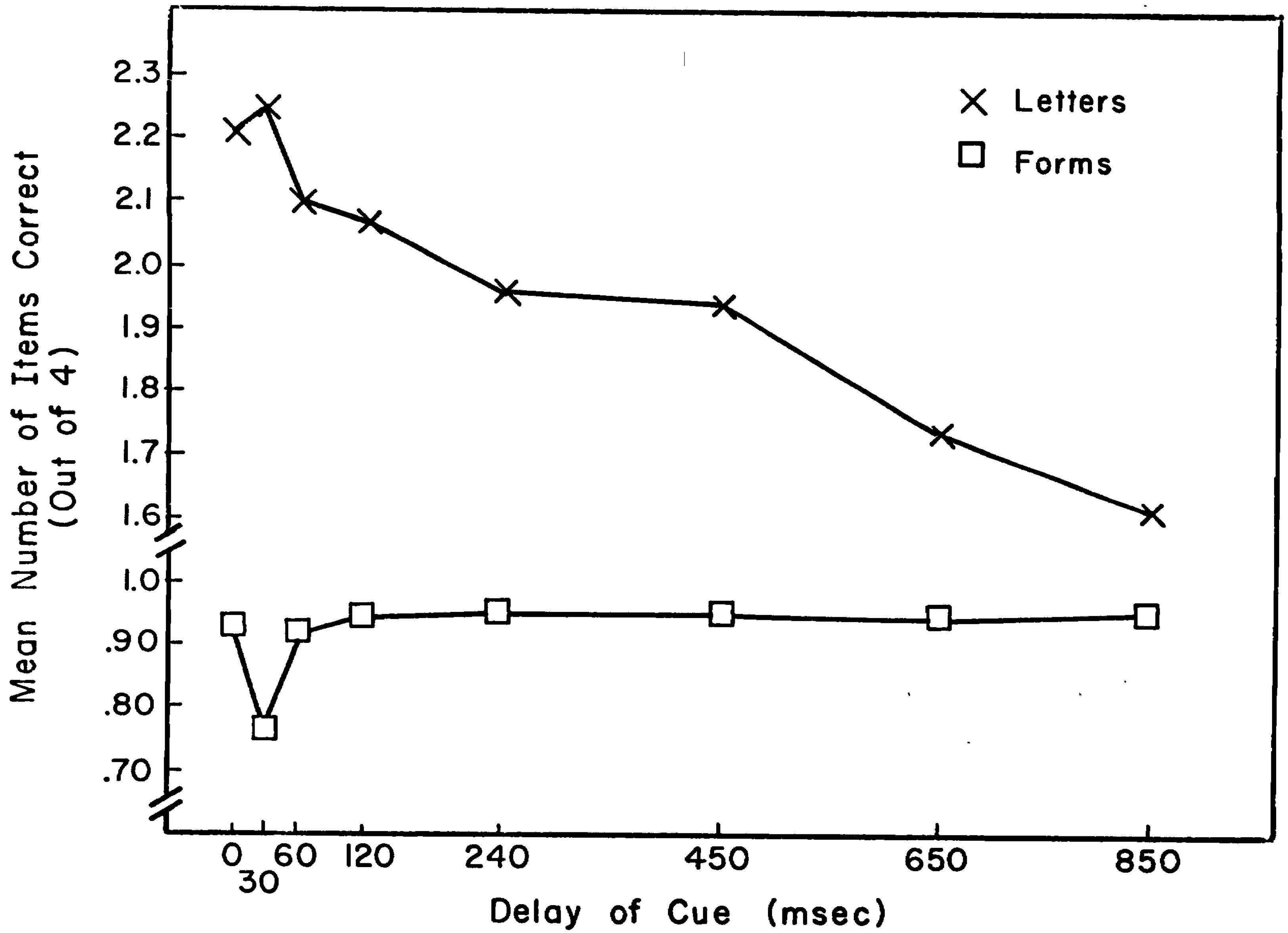
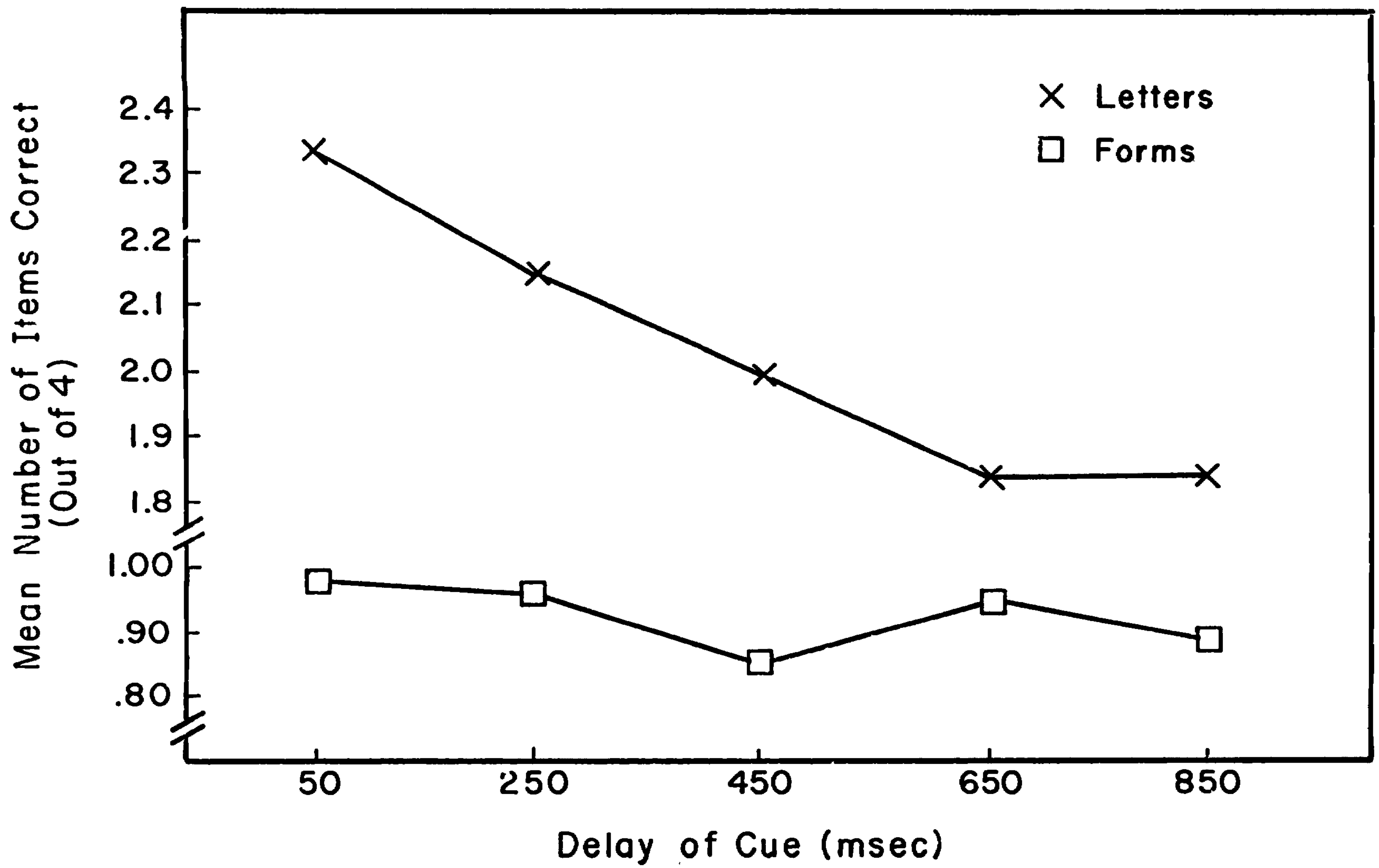
Figure Captions

Figure 1. Mean accuracy as a function of delay of the cue with letters as stimuli in Experiments I and II.

Figure 2. Mean accuracy as a function of delay of the cue with forms as stimuli in Experiments I and II.


Mean Number of Items Correct
(Out of 4)
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.0
.90
.80
.70
Letters
Forms
0
30
60
120
240
450
650
850
Delay of Cue (msec)



Mean Number of Items Correct
(Out of 4)
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.00
.90
.80
50
250
450
650
850
Delay of Cue (msec)
Letters
Forms

Binocular and Dichoptic Cuing in Iconic Memory

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An experiment to localize iconic memory neuroanatomically involves use of dichoptic presentation with the stimulus array to one eye and the bar marker cue to the other eye. Results from other experiments offer strong suggestions as to what one would expect in this instance. For example, both backward masking and metacontrast are effective with dichoptic presentation (Averbach & Coriell, 1961; Schiller, 1965). The literature is not very clear on the magnitude of the effect of dichoptic vs. monoptic presentation but it is generally conceded that the dichoptic case is less effective than the monoptic one. One could, quite reasonably attribute the difference in magnitude between the monoptic vs. dichoptic procedures to retinal processes. That is, a portion of masking operates at the retina and with dichoptic presentation, the retinal component is removed from the masking function.

The masking and metacontrast data suggest that iconic memory has a cortical component inasmuch as a binocular interaction is sufficient to obtain some reduction in performance. Using a different approach, Lefton and Dick (1973) have shown that the rate of decay is not influenced whether a multi-item cue is given visually or auditorily. It is unlikely that an auditory cue would have much of an influence at the retina and therefore, the authors assumed that iconic memory must be cortical. In fact, Dick (1972) has claimed that an auditory cue must have its effect after masking. Similar suggestions are contained in the work of Turvey (1973) and von Wright (1972).

There are several reasons for examining the locus of iconic memory using binocular and dichoptic cues. First, there is a marked difference between the types of errors made in a bar marker experiment (visual probe) and the errors made in a partial report experiment in which the subject reports a number of items (multi-item cue). Perhaps multi-item cues and single item cues operate in entirely different ways. Thus, it is possible that iconic memory is retinal, as some early theorizing implies. Accordingly, a multi-item cue might affect short-term memory or recall processes without influencing iconic memory directly. If iconic memory were entirely retinal, then one would expect differences in the rate of decay as a function of binocular or dichoptic cuing because the cue would have to occur at the same retina as the stimulus to obtain decay. If iconic memory were entirely cortical, there would be no difference in decay between the binocular and dichoptic conditions.

Method

Subjects. The subjects were 12 laboratory personnel. All Ss had normal or corrected to normal vision and were naive to the purpose of the experiment.

Stimulus Materials. A set of stimulus cards was prepared consisting of letters of the alphabet. The set of stimulus items consisted of ten items; six different items were placed on each stimulus card. The sequences were generated randomly with a restriction that each item appear in each of the six possible positions equally often. This allowed complete counterbalancing with respect to item and position through the set of 80 cards. Cue cards consisted of arrowheads which occurred above and below one of the positions previously occupied by an item.

The letter cards were prepared by placing Letraset (Futura Bold, No. 108, capitals) on white cards. When viewed in the tachistoscope, all stimulus sequences subtended a visual angle of 3^{o} 20' x 20'. The width of an individual item was about 16' of visual angle.

Procedure. The stimuli were shown in a Gerbrands three-channel tachistoscope. The stimulus sequence was the fixation field, stimulus, fixation field for a variable interval, the cue, and then the fixation field again. The cue followed the stimulus at delays of 0, 30, 60, 120, 240, or 480 milliseconds. The fixation point was centered in the field and fell just below the stimulus item and between positions three and four. The duration of the stimulus and cue were both 50 milliseconds; the background luminance of the stimulus and cue fields equated at 1.0 ft-L in the dichoptic condition.

For each S, the first eight trials within a condition constituted practice, followed by 72 experimental trials. The cue position and delay were counterbalanced across the set of 72 experimental trials, and each position was sampled equally often at each delay, thus allowing for two replications of the 36 stimulus position by delay combinations. For a given S the delays and positions were presented in a random order; these were then counterbalanced across Ss. As a result, Ss reported different items from each card. The S responded verbally by naming the item requested. Polarizing filters were used in the dichoptic condition such that the letters were shown to the left eye and the cue to the right eye. In the binocular condition, the letters and the cues were presented to both eyes.

Results and Discussion

The number of correct responses were tabulated for each delay in both the binocular and dichoptic conditions. The results are shown in Fig. 1. From the figure it is clear that both the binocular and dichoptic conditions show decreases in accuracy as the cue is delayed. There is no interaction between the delay and the viewing conditions which is consistent with the notion that decay occurs after the two inputs have combined. The difference between the binocular and dichoptic conditions probably reflects a) an advantage due to binocular summation that is possible in the binocular condition but not in the dichoptic condition b) a small effect due to differences in the luminance for the two conditions and c) rivalry between the eyes in the dichoptic condition.

The present findings clarify certain aspects of the data of Jacewitz and Lehmann (1972). They presented a matrix of letters to one eye and various interference (masking) conditions to the other eye. An auditory cue indicated which of three rows to report. They found greatest decay without any interference and least decay with a masking grid. One would expect a change in the

rate of decay in their situation because of the masking effects. Indeed, as one delays the mask an increase in performance is usually observed. By contrast, decay shows a decrease in performance as the cue is delayed. Thus, the combination of the effects of decay and masking probably underly the interaction between masks and delay of the cue.

In general, the present results suggest that decay occurs at a cortical level and has little in the way of a retinal component. Many other findings are consistent with this view. Because decay is observed with an auditory cue, one would expect that decay must be relatively central. There is no known centrifugal mechanism which would provide a basis for an auditory input affecting the processing at a retinal level. Furthermore, Dick (1972) has shown that the effects of a cue must occur after masking has had its effect. Because dichoptic masking is a known phenomenon (Schiller, 1965) and visual persistence is uninfluenced by dichoptic vs. monoptic viewing (Haber & Standing, 1969) the most reasonable conclusion seems to be that decay is a result of cortical function. Recent work by Turvey (1973) on visual backward masking is totally consistent with this view.

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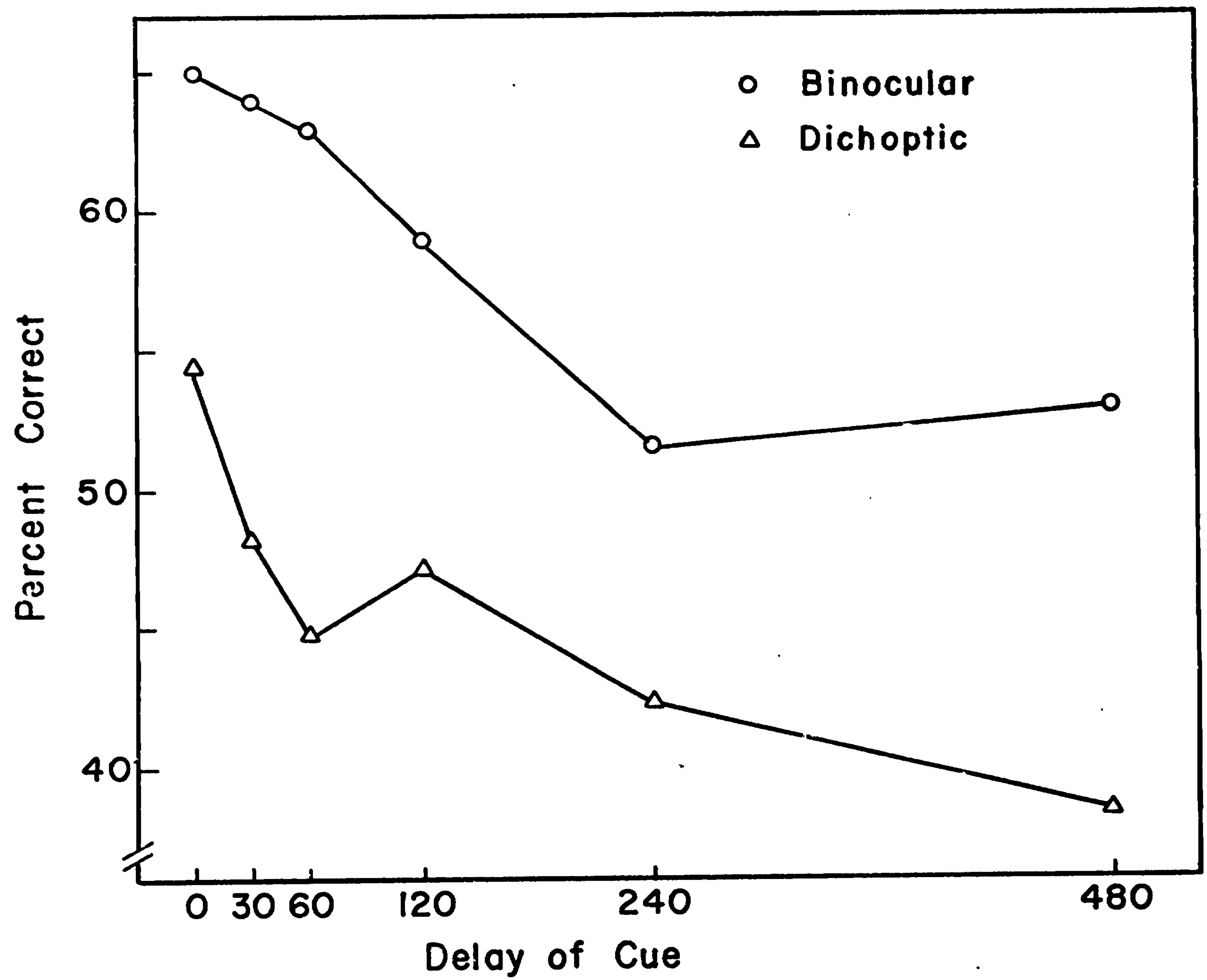
Figure Caption

Figure 1: Accuracy as a function of delay of the cue for both binocular and dichoptic viewing conditions.



Binocular
Dichoptic
Percent Correct
60
50
40
0 30 60 120 240 480
Delay of Cue

Parallel and serial processing in tachistoscopic recognition: Two mechanisms

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In a multi-item tachistoscopic display, accuracy is not consistent across the array of items. In the typical experiment letters in peripheral retinal locations are reported more accurately than letters in more central positions. Woodworth (1938) suggested that the phenomenon was due to "spatial masking" created by adjacent letters. The existence of performance inequalities within a display is well established, although the specific relation of position to accuracy varies from experiment to experiment. One implication of this result bears on the kinds of processing that underlie performance on tasks of this sort. Because simultaneously presented elements seem to interfere with each other, the inference must be that some parallel processes are taking place. It is doubtful if such effects are of retinal origin, since "spatial masking" does not depend on the physical spacing between items (e.g., Harcum, 1964). Parallel processes in visual analysis are, of course, to be expected since the input is parallel.

Just as the "spatial masking" effects imply parallel processing, many other data suggest that portions of visual analysis are done in a serial manner. Since the studies of Sperling (1960), the evidence showing a rapid decline in accuracy during the first ¼ to ½ second following termination of a visual display has been interpreted as support for a serial mechanism. That is, if all of the items were processed simultaneously, there would be no decline in accuracy as a function of delay as long as analysis of the items commenced immediately. Since a decline is obtained, however, it is more likely that this procedure reflects serial mechanisms. The act of responding, obviously, must be a serial process since language and verbal behaviors are organized in a serial manner.

In tachistoscopic recognition, input is parallel and output is serial. At some point the multiple parallel input must be converted into a sequential mode for multiple output. Since the position effect reflects parallel phenomena and post-exposure cueing apparently reflects serial phenomena, it would seem consistent to suggest that two different mechanisms are involved. The relation of these two hypothetical mechanisms was explored in the present experiments. The logic of the experiments was as follows: accuracy of report of part of a display should depend upon the total number of items available in the display. A visual noise mask can alter accuracy presumably by changing the number of available items. Thus, if a visual noise mask is added to one part of the display, accuracy should increase on other parts because the mask should reduce the number of available items and thus reduce the total amount of necessary processing. Further, the greater the number of unreported items masked, the higher should be the accuracy. This predicted outcome would support a parallel mechanism by way of altering the amount of "spatial masking".

By contrast, the use of a post-exposure indicator yields evidence about decay characteristics of information in the visual system and serial properties of the system. Since this is postulated to be different from "spatial masking", the amount of decay observed should not be altered by a reduction in the amount of "spatial masking". In short, increasing the number of items masked should increase accuracy but delaying a report cue should decrease accuracy and both effects should be observed simultaneously. These predictions were tested in two experiments in which three rows of letters were presented and the subject asked to report one of them. The specific hypotheses were tested by manipulating the number of rows masked, the delay of the mask and delay of the report cue.

Experiment I

Subjects--The Ss were 24 summer students at Lake Forest College; all were volunteers.

Stimuli--Three sets of 24 cards were prepared by placing Deca-Dry lettering (Style #2736) on white cards. There were 12 letters per card with no repetitions; letters were randomly drawn with the requirement that no letter appear twice in the same sequence. The 12 letters were arranged in three rows of four with each letter subtending a visual angle of 27' and the entire display subtended an angle of $2^{o}30' \times 2^{o}30'$. Patterned masks consisting of cross-hatching were prepared with India ink and a Leroy pen. A template was used to draw the lines evenly spaced. When viewed in the tachistoscope, the grid subtended an angle of $30' \times 3^{o}40'$. Two sets of 48 masks were prepared; each incorporated 0, 1 or 2 grids in every possible combination.

Procedure--The stimuli were shown in a Scientific Prototype three field tachistoscope. The letters were presented in Channel 1 for 50 msec. and the masks in Channel 2 for 75 msec. The blank field was used to provide an adapting field (about 8 ftL) containing a small black fixation point. The fixation point was centered midway in the middle row and was present at all times except when one of the other stimuli was shown. Under the no mask condition a blank card was flashed in place of the grid. This control is necessary because S can detect the switch from one field to another in the tachistoscope and this switch may have a disruptive effect on performance.

Design--A partial report procedure was used in which the S was presented three rows of letters and asked to report part of the display, i.e., one of the rows. Coded auditory tones were used as report cues; a high tone (1000 Hz) indicated report of the top row, a middle tone (400 Hz) report of the middle row, and a low tone (200 Hz) report of the bottom row. The interval between the termination of the target and the initiation of the tone was either 0 or 200 msec. A visual mask was used and either followed

the stimulus display immediately (0 msec.) or after a delay (200 msec.). The number of rows that were masked was also a variable with 0, 1, and 2 of the three rows being masked. For a given row to be reported, e. g., top, this necessitates four masks: no mask (a blank card); one grid on the bottom row; one on the middle row; two grids, one each, on the middle and bottom rows. Thus, there were four variables involved: (a) delay of the report cue (tone), (b) delay of the mask, (c) row reported, and (d) row masked. This constitutes a total of 48 experimental conditions. Each _S_ was tested on two randomized blocks of these 48 conditions, giving a total of 96 experimental trials. In addition, each _S_ was given 24 free recall practice trials prior to the experimental testing. In all cases, _S_ reported the letters verbally.

Results and Discussion

The number of letters correctly reported were used as the dependent measure in a number of analyses. One overall analysis of variance (_Ss_ x number of masks x delay of tone x delay of mask x row reported) was carried out which showed a) all main effects to be significant ($p < 0.001$), and b) the interactions of number of masks x delay of mask, number of masks x row reported, and delay of masks x row reported (all with $p < 0.001$). A second set of analyses involved separating the data into three categories according to the number of rows masked. The mean squares for these three analyses are presented in Table 1. The characteristics of the overall analyses are preserved in Table 1, in that comparisons across a row yield an index of the relative contributions of each variable relative to the number of rows masked.

In Figure 1 are shown the effects of the number of masks, the delay of the mask and delay of the tone. From the figure it is clear that there is little difference between no mask and one mask on overall performance. Part of this lack of difference is due to the fact that the one-mask condition actually contains two conditions. For example, if the top row was reported, either the middle or the bottom row might be masked. There should be less facilitation, in this case, by masking the bottom row than by masking the middle. A more detailed analysis suggests that the single mask is more effective if it falls on an adjacent row than it is if removed by a row. Therefore, as displayed in Figure 1, the condition with one mask underestimates the beneficial effect of masking.

The two-row masked condition shows clearly the benefit of the masking stimulus and the effects of delaying the cue. There is, however, a confound in this condition. Having two rows masked immediately constitutes a complete (but negative) visual cue, because Ss were told that they would not have to report a row that was masked. This would be especially true for the case in which there were two masks occurring immediately after the display. The general effect of redundant cueing should be to reduce the magnitude of the decline in accuracy due to delaying the tone. Nevertheless, the data indicate that the tone has an effect since a delayed tone produced lower accuracy than an immediate tone (Table 1).

Experiment II

In Experiment I, the occurrence of the mask could have provided information about which row to report since the Ss were instructed that they would not have to report a masked row. This problem was eliminated in the second experiment by requiring report of all possible combinations, that is, sometimes S was asked to report a row that had been masked.

Method

Subjects--The Ss were 23 undergraduates at the University of Rochester taking an introductory course in psychology. Participation in the experiment fulfilled part of the class requirement. All Ss were tested on a Snellin chart for visual acuity prior to participation in the experiment.

Stimuli--The stimuli were some of those used in Experiment I.

Procedure--The stimuli were presented in a Gerbrands three-field tachistoscope. The balance of the procedure was identical to Experiment I. The visual angle of the display was $3^{o}20'$ x $3^{o}20'$ shown at a background luminance of about 2 ftL. The exposure durations for both the mask and stimulus were 50 msec.

Design--The four variables of Experiment I were factorially manipulated in the experiment. These consisted of (a) the seven different masks, (b) the three different rows that could be reported, (c) the delay of the report cue, and (d) the delay of the mask. Altogether, this gives 84 experimental combinations; the increase in conditions is due to the report of masked rows. To achieve this, 42 stimulus cards were presented twice; Ss were cued to report different rows on two occasions, however. In addition, each S was given 12 practice trials before presentation of the experimental conditions. In all cases, the Ss reported the letters verbally.

Results and Discussion

As in Experiment I, two sets of analyses were applied to the number of letters correctly reported. The mean squares for the individual analyses on each of the masking conditions is presented in Table 1. The means are shown in Figure 2 and Table 2. An analysis of variance applied to the data for unmasked row report showed the following effects to be significant: delay of the cue, delay of the mask, the number of rows masked, and the row reported ($\underline{p} < .01$). In addition, virtually all of the interactions involving the row reported were significant ($\underline{p} < .01$), as in Experiment I. Most of these interactions are due to the fact that there is a bias toward the middle row (where the fixation point was located) and a slight bias away from the bottom row. Manipulations of the type of mask and mask-delay dramatically change the relation of these biases. The data indicating the bias of row reported may seem to be a confounding result, but it is an important one to which the discussion will return. Before discussing the general implications, it is appropriate to consider some of the other effects in detail.

The greater the amount of the display that is masked, the higher the performance for report of unmasked rows. In addition, the mask is minimally effective when it is delayed by 200 msec.; in fact, performance is about the same for both masked and unmasked rows when the mask is delayed by 200 msec. The result that the number of rows masked changes performance has some implications for the type of processing that takes place. Clearly, processing cannot be carried out entirely in a serial manner, otherwise masking an unreported row would have no effect on a row that was reported. This result parallels that of Mewhort (1967) in which he showed that the familiarity of unreported material influences accuracy of reported material.

Delaying the report cue generally resulted in a reduction in accuracy; this effect was enhanced by masking one or two rows although the effect interacts with delay of mask. Without a mask, spatial interference appears to reduce the effects of decay. Since the magnitude of the decay effect increases as a result of masking, this suggests that decay is a postmasking phenomenon and is clearly consistent with the two mechanism hypothesis.

Conclusions and Implications

Taken together, the data on masking unreported rows and delay of the report cue suggest two different mechanisms. That is, the mask seems to affect the system at a point at which processing occurs in parallel and before complete identification of the stimulus has occurred. The report cue probably has its effect later in the processing sequence and in such a way that processing appears to be serial. The fact that an auditory signal

yields evidence related to visual processing suggests that the locus of decay takes place relatively advanced in the system. In somewhat different terminology the mask may affect preattentive processes but the cue may affect attentive processes (Neisser, 1967).

The mechanisms might operate in the following way. A multi-element input establishes an iconic memory. Information in iconic memory is not stored passively, but rather a number of operations are performed on its contents. (In this context, iconic memory describes post-stimulus but pre-verbal analyses.) The analyses carried out at this point mignt include spatial position, shape, orientation, etc. This parallel system is connected to a sequential system in which verbal labels are attached. Although the visual analysis may be complete on an item, this does not automatically mean that the item will get transferred into short-term memory. The order of transfer is determined either by a self-induced set (e.g., the use of reading habits) or by experimental instructions. A report cue would be such an experimental instruction. If such a cue is delayed, S will begin to transfer items according to his own instructions, including a bias toward particular rows. When the cue arrives, he will have to switch attention on a certain proportion of the trials and alter the order of transfer. Furthermore, a switch in attention would require a finite amount of time.

Several predictions are generated from the attention-switching hypothesis. First, decay would be observed when attention is focused on the wrong part of the stimulus and a switch would be required. Accuracy is lower because of a) the time spent on the wrong portion of the display and b) the time required for a switch in attention. Holding (1971) has reported data relevant to this prediction. He asked Ss to guess which row they would be asked to report. Holding presented a three-row display and found that the accuracy of the guess about the row to be reported was inversely related to the amount of decay observed. If S correctly anticipated the correct row, no decay was observed. If S was off by one row, some decay was observed and if he was off by two rows, more decay was observed. The inequality of row accuracy in the present experiments is consistent with Holding's interpretation. Although the row x delay of cue interaction is not significant this is probably due to the small number of delays used and to the presence of the mask. The second prediction has to do with the switch itself. On a full report trial, all of the items would be reported and hence a switch would not be needed. This suggests that accuracy in full report should be slightly higher than that of partial report. Taking output interference into account, Dick (1971) has shown that, indeed, full report is more accurate than partial report.

The results reported in this paper and the interpretation given to them are in accord with other data (Eriksen & Colegate, 1971; Eriksen & Rohrbaugh, 1970). Eriksen and Colegate (1971) presented eight letters

which were preceded, simultaneous with or followed by one or two indicators. Their results show that an indicator that precedes the display leads to better accuracy than one following or simultaneous with the display. Their interpretation is in line with the present one, namely: that the cue affects the order of transfer of items from iconic to short-term memory. Their data, the present data, and those of others (e.g., Mewhort, Merikle, & Bryden, 1969) all suggest that transfer is a serial mechanism.

At the same time, however, the results of the masking manipulation in the present experiments provide clear evidence for a parallel mechanism. Furthermore, other data suggest the existence of parallel mechanisms. For example, McIntyre, Fox, and Neale (1970) asked subjects to detect a target letter embedded in a matrix of noise letters. They varied the redundancy of the noise elements to each other and the similarity of the noise to the target letter. They found that increased redundancy and decreased similarity both served to increase the proportion of correct detections over a control condition. The authors suggest that redundancy has its effect at a point in the system where the input is still parallel. Their interpretation is also consistent with the findings of Dick (1970) who showed that the amount of structural redundancy was not related to post-exposure decay, but was related to performance.

In summary, the present data provide evidence for both serial and parallel mechanisms. This suggests that the question whether stimuli are processed in serial or parallel bypasses more important issues. A similar point has been made by Garner (1970) in discussing separable and integral dimensions. Inasmuch as the present data provide evidence for both serial and parallel processing on the same set of stimuli, Garner's point may be generalized. In addition to the kind of stimuli employed, one must consider the points in the processing sequence that are being sampled. There is also the intriguing possibility that differences between parallal and serial processing could be used as a tool of analysis of the organization of sensory and cognitive processes.

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Table 1 Modified source tables for Experiments I and II. The entries are mean squares.

	Experiment I	Report Unmasked			Experiment II	Report Unmasked			Report Masked	
	df's	no Mask	one Mask	two Masks	df's	no Mask	one Mask	two Masks	one Mask	two Masks
Total Subjects	287	3.70	(4.15)	5.18	275	1.51	(1.79)	1.85	1.43	(1.26)
Delay of Mask (DM)	1	.89	55.00	282.03	1	2.09	19.97	91.60	31.34	160.88
Error (DMXSs)	23	1.87	3.08	4.08	22	.94	.81	1.55	.95	1.76
Delay of Tone (DT)	1	8.68	6.67	34.03	1	13.04	16.35	1.92	21.48	.59
Error (DTXSs)	23	1.33	1.97	2.02	22	1.37	.50	.96	.81	.80
Row Reported (R)	2	61.56	101.72	54.01	2	4.22	10.77	8.11	8.01	2.30
ϕ_1 (M vs. T + B)	1	75.11	39.38	79.51	1	4.17	21.20	15.02	4.53	2.00
ϕ_2 (T vs. B)	1	48.00	164.06	28.52	1	4.26	.33	1.22	11.50	2.61
Error	46	5.50	3.26	4.82	44	.68	2.45	1.76	.68	.93
DMXDT	1	6.12	2.25	.17	1	2.45	3.67	8.00	20.38	.36
Error (DMXDTXSs)	23	3.46	1.45	1.47	22	1.94	1.13	1.08	.86	.67
DMXR	2	4.35	2.94	15.17	2	2.09	.80	5.75	19.30	3.88
ϕ_1 (M vs. T + B)	1	8.51	1.06	25.00	1	1.04	.40	8.62	26.09	1.24
ϕ_2 (T vs. B)	1	.19	4.82	5.33	1	3.13	1.20	2.88	12.52	6.52
Error (DMXRXSx)	46	1.62	2.00	2.48	44	.97	1.11	1.01	.41	.66
DTXR	2	6.51	2.42	4.04	2	1.70	3.79	2.31	.97	.39
ϕ_1 (M vs. T + B)	1	.01	3.90	1.56	1	3.20	7.50	2.22	.18	.66
ϕ_2 (T vs. B)	1	13.02	.94	7.52	1	.20	.07	2.40	1.76	.13
Error (DTXRXSs)	46	1.88	1.48	1.82	44	1.23	.61	.91	.81	.67
DMXDTXR	2	1.12	3.54	5.51	2	1.93	2.16	.44	25.17	.19
ϕ_1 (M vs. T + B)	1	2.25	1.32	8.03	1	.18	4.31	.22	.26	.26
ϕ_2 (T vs. B)	1	.00	5.75	3.00	1	3.67	.00	.66	50.09	.13
Error (DMXDTXRXSs)	46	1.42	1.42	1.29	44	1.33	.94	.78	1.03	.59

Table 2

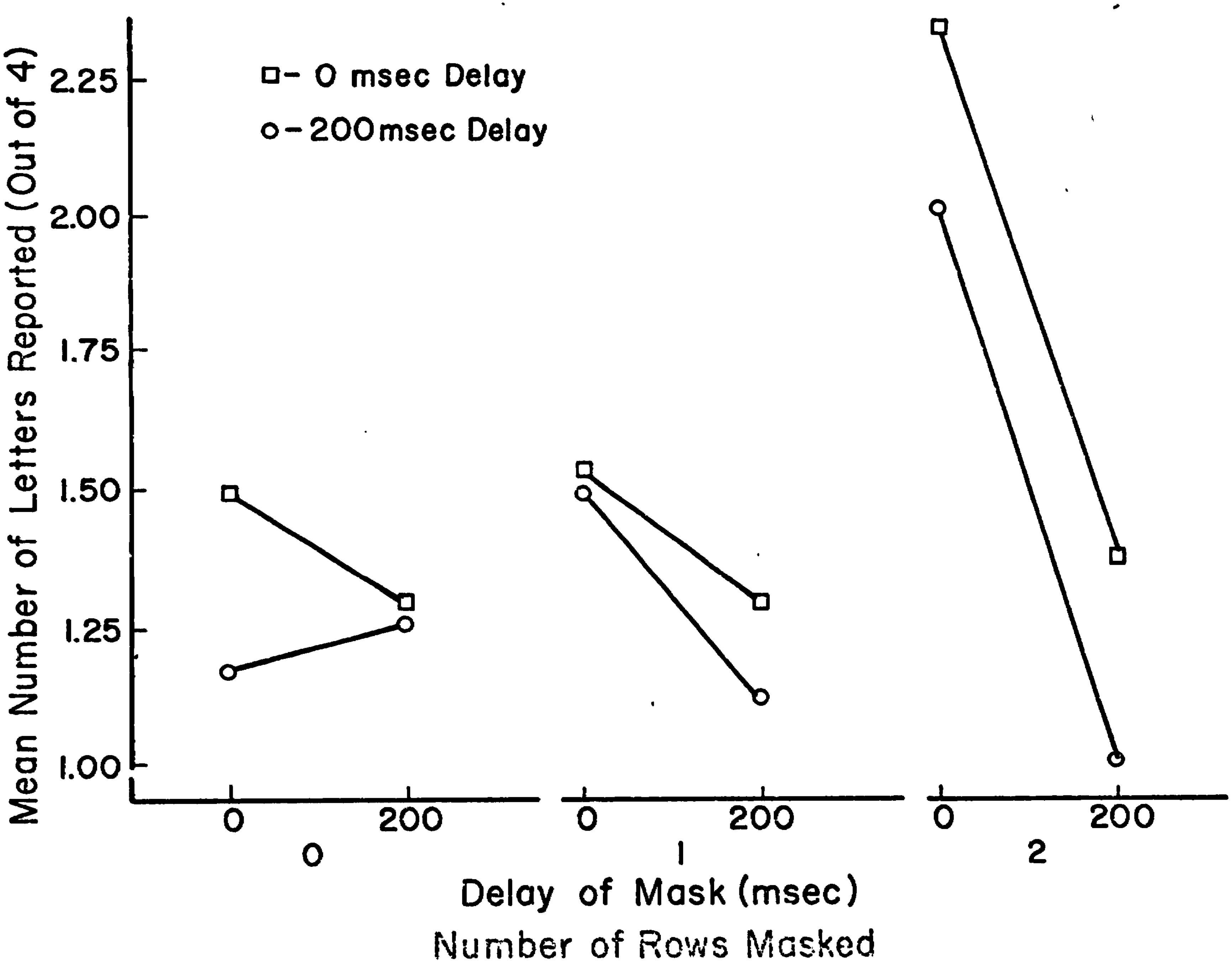
Mean Accuracy (out of 4)
for the
Various Conditions in Experiment II

		Delay of Cue					
		0 Msec			200 Msec		
		Row Reported			Row Reported		
Rows Masked	Delay of Mask	T	M	B	T	M	B
0	0	1.78	2.74	1.39	1.65	2.26	2.13
	200	1.39	1.91	2.04	1.87	1.70	1.44
T	0	0.04	3.30	2.26	0.09	2.17	1.87
	200	1.00	2.35	1.70	0.87	1.96	1.13
M	0	2.70	0.09	2.00	2.04	0.04	2.00
	200	1.70	2.52	1.22	1.44	2.26	1.83
B	0	2.00	2.44	0.09	1.17	2.26	0.09
	200	2.22	2.22	1.00	1.13	2.70	0.30
T&M	0	0.13	0.04	3.26	0.13	0.30	2.48
	200	0.87	2.44	1.17	0.74	2.39	0.96
T&B	0	0.04	2.87	0.04	0.04	2.70	0.00
	200	1.22	1.96	0.56	1.13	2.30	1.00
M&B	0	2.70	0.30	0.22	2.04	0.22	0.17
	200	0.96	1.22	1.04	1.39	1.78	1.09

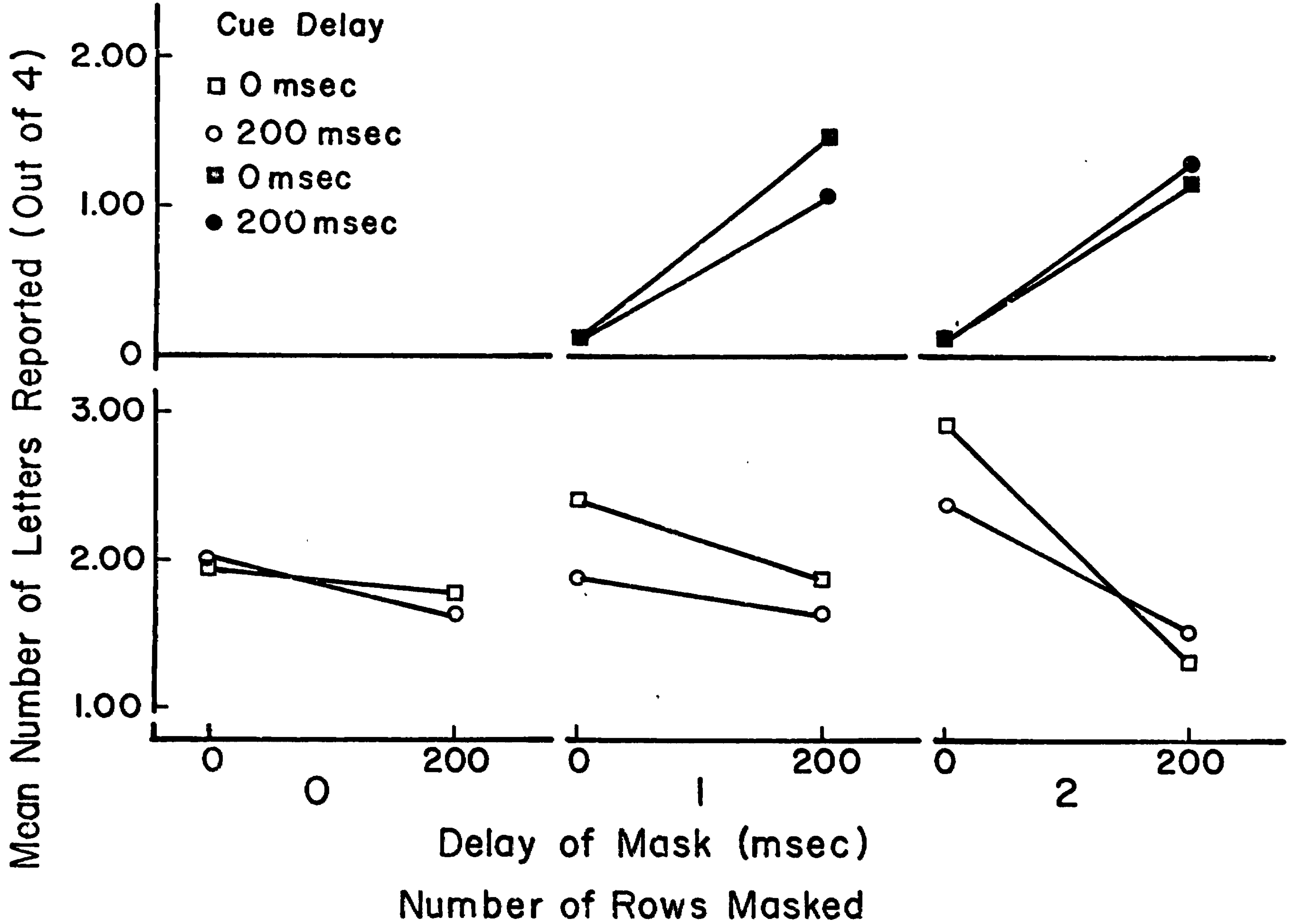
Figure Captions

Figure 1: Mean accuracy of report as a function of delay of the mask and number of rows masked. Delay of the cue is the parameter. For the zero mask condition the mask delay refers to the delay in switching to a blank masking field.

Figure 2: Mean accuracy of report as a function of delay of the mask and number of rows masked. Delay of the cue is the parameter. Filled symbols represent report of masked rows; open symbols report of unmasked rows. As in Experiment I, delay of the unmask condition refers to the delay of a blank field.



□- 0 msec Delay
o-200msec Delay
Mean Number of Letters Reported (Out of 4)
2.25
2.00
1.75
1.50
1.25
1.00
0
200
0
200
0
200
0
1
2
Delay of Mask (msec)
Number of Rows Masked


Cue Delay
0 msec
200 msec
0 msec
200 msec
2.00
1.00
0
3.00
2.00
1.00
Mean Number of Letters Reported (Out of 4)
0
200
0
200
0
200
0
1
2
Delay of Mask (msec)
Number of Rows Masked

ON THE ROLE OF VERBALIZATION IN TACHISTOSCOPIC RECOGNITION AND ICONIC MEMORY

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One important difference between letters and unfamiliar geometric forms is the amount of verbalization possible on two materials. We know, for example, that if adults are asked to report a single row of letters they will be more accurate than with a single row of geometric forms(Bryden, 1960). Several explanations can be offered for this result. For example, it has been shown that familiar letter sequences are processed faster than unfamiliar letter sequences (Mewhort, Merikle, & Bryden, 1969). Subsequent work by Mewhort (1972) suggests that a portion of the difference in the rate of processing is due to differences in the rate of transfer from iconic memory to short-term verbal memory. According to this interpretation, subjects perform better on familiar materials because they can verbalize the names faster and hence rehearsal is easier, which would be due to either differences in speed of rehearsal or the number of items that can be rehearsed as a result of one presentation.

Not all tasks, however, yield performance differences with manipulations in the familiarity of the stimulus materials. For example, Posner and Mitchell (1967) compared reaction times for letters and geometric forms. They found that subjects were equally fast on matching two items whether the items were letters or geometric forms. Similarly, Lefton (1973) has found that order of approximation to English had no effect on the rate at which subjects could locate a critical item in a letter sequence. There is an important difference between the free recall studies and the reaction time studies, namely: in the reaction time studies the subject does not have to report verbally any of the items. His response is motor and therefore may involve different mechanisms in the analysis of the information necessary to perform the task.

In iconic memory studies, the effect of familiar materials is less clear. Many, many studies have shown a decrease in accuracy as a report instruction is delayed with respect to the stimulus exposure. Typically, these studies involve alphabetic stimuli; the particular procedure does not seem to be critical (Averbach & Coriell, 1961; Sperling, 1960). By contrast, when difficult-to-label geometric forms are used as stimuli, the results will depend upon the procedure used. For example, if the subject is asked to report just one form, accuracy declines as a function of delay of the cue (Dick, Loader, & Lefton, 1973). When the subject is

required to report a number of such forms, accuracy is uniformly low [illegible] and no decay is observed (Dick, 1967). Furthermore, the effect is not dependent upon how the subject reports the material in the multi-item report condition; neither written nor verbal report yield an effect of delaying the report cue (Dick & Lefton, 1973). The geometric forms are clearly more difficult even in the single item report case (Dick et al. 1973) and consequently suggest that the demands on processing capacity must be much greater for the unfamiliar forms than for letters. To say that the system is overloaded, however, does not provide any hints about the function of the individual components of the system.

Apparently, the major difference between familiar materials and unfamiliar materials is the amount and rate of verbalization possible. It has long been known that verbal materials labels may influence the way in which forms are reproduced (Carmichael, Hogan, & Walter, 1932; Herman, Lawless, & Marshall, 1957). Further, it has been claimed that perceptual assimilation is influenced by verbal labels (Bruner, Busiek, & Minturn, 1952). More recently, several studies have shown that short-term memory is facilitated by the availability of verbal labels. The labels seem to operate by means of facilitating rehearsal because more items can be entered into rehearsal within a given time period and hence recall is improved. The benefit of labels is reduced or even eliminated by requiring an interference task of counting backwards, clearly indicating the rehearsal component (Santa & Rankin, 1972).

An alternitive explanation is that the verbal labels affect perceptual processing rather than the results of perceptual processing. One implication of this view might be that iconic memory should be longer for familiar than unfamiliar items. This implication is not supported in as much as the rate of decay is the same for both familiar and unfamiliar items (Dick et al. 1973; Mewhort, 1967). It is also unlikely that verbal labels affect perceptual processing in any other way. Del Castillo and Gumenik (1972) presented familiar and unfamiliar forms sequentially. They varied the rate of presentation and found increases in performance for the familiar materials and the rate was slowed. Performance on the unfamiliar items was constant. As subjects gained experience with the materials, however, the unfamiliar materials also showed improvement. The authors account for this latter result by suggesting that subjects develop labels through experience and it is the use of the labels that allows performance to increase.

In the present experiments, verbal processes were examined in relation to perceptual processing in an iconic memory task. Specifically, subjects were trained on labeling so that they would be able to apply labels faster. Over a series of experimental sessions, performance improved markedly but there was no change in level of accuracy as a function of delay of the cue. In a second experiment, native and non-native readers of Hebrew were tested on both Hebrew and Roman alphabets. The native readers of Hebrew showed loss of information as a function of delay of the cue with both materials; however, the non-native readers showed loss only for the Roman alphabet.

Experiment I

Method

Subjects.--The subjects were three undergraduates at the University of Waterloo. Each was paid $2.00 an hour for his participation.

Stimuli.--Four sets of stimuli were used in the experiment. One set consisted of 72 cards with eight letters per card, arranged in two rows of four. These stimuli were used to determine base line performance for each of our subjects in a partial report task. The second set of stimuli consisted of 78 cards with eight forms per card arranged in two rows of four. These cards were also used in the pre-testing session for partial report and also for post-training testing with partial report. The third set of cards consisted of one form per card and were used for serial learning during the training sessions to familiarize the subject with the forms. The fourth set of cards contained one form and one letter per card and were used for paired associate sessions during the training period. The forms were generated by randomly selecting two or three lines as illustrated in Figure 1.

Procedure.--Each subject was tested for 21 sessions where a session is defined as consisting of 78 trials. The 21 sessions were broken down into five different tasks. Task 1 consisted of four sessions of partial report of letters in which the subjects reported either the top row or the bottom row verbally. The second task consisted of three sessions of partial report on forms during which the subject drew the forms on specially prepared templates. Task three consisted of five sessions of serial learning. Each trial consisted of the presentation of eight forms in sequence after which the subject drew those eight forms on the template sheets. The serial learning task served to familiarize the subject with the 26 forms that were employed. Task 4 was designed to train the subjects to label the 26 forms. It consisted of five sessions of paired associate learning, each trial consisted of the presentation of eight pairs, a form with a letter response and then followed by a test of those eight forms alone. Finally, in Task 5, the subjects returned to the tachistoscope for four sessions of partial report on forms during which they labelled the forms with their letter names.

For the partial report task, the stimulus items were exposed for 50 msec followed by a coded auditory tone of either 200 or 1,000 Hz which was of one second in duration. These cues indicated to report either the top row or the bottom row. The delay of the cue was manipulated systematically with interstimulus intervals of -50, 50, 150, 350, 750 msec. During the serial learning and paired associate learning no systematic timing was employed although the experimenter endeavored to present the items at a relatively constant rate of approximately three seconds per card. During the last two sessions of the paired associate task, the subject was shown a tachistoscopic stimulus card and asked to label the forms.

Results and Discussion

Performance improved considerably as a result of the training; in fact, performance was about double after training. Although some of the improvement is likely due to simple familiarization with the geometric forms, it is also clear that the training on labelling facilitated performance. In the final sessions, subjects were required to label the forms which would involve the training that they had received. Although performance improved, there was no evidence that the delay of the cue affected performance. There is no question that the subjects knew the forms and the appropirate label as indicated by the paired-associate learning data. From this it would seem that not only do the labels have to be highly overlearned but also the specific experience with the materials may play a role. For example, Bryden (1960; Bryden, Dick, & Mewhort, 1968) has shown that subjects report letters more rigidly than numbers although both are about equally familiar. For these reasons, it seemed inappropriate to continue training. Instead, we approached the problem by studying native and non-native readers of Hebrew.

Experiment II

In Experiment I, verbal training improved performance but did not provide any evidence of loss of information as a cue was delayed. These results may have been due to either of the following possibilities. First, the amount of practice given the subjects clearly did not approximate the practice they have had on letters. Second, the experience given the subjects was not of the form that one obtains during activities such as reading. That is, the practice on forms was not provided in such a way as would be consistant with reading experience. From other work we know that the use of spatial information is dependent upon experience (Dick, Dick, & Eliot, in preparation). In that experiment, fourth grade subjects did not show a decline in accuracy with cue delay when reporting letters and numbers according to rows. Although fourth graders have had experience reading, they apparantly were not able to take advantage of the spatial information.

Such considerations lead to the testing of native and non-native readers of Hebrew. Non-native readers of Hebrew should, in some ways, be equivalent to fourth graders in the sense of showing low performance and no decay on Hebrew characters. Native Hebrew readers however should be much better in performance and should show decay. For control purposes, both groups were also tested in the Roman alphabet.

Method

Subjects.--Six subjects were tested in the experiment. Of the six, three were native Israelis for whom Hebrew was the first language read; they had lived in the United States two years at the time of testing. The other three subjects were non-native; all three had learned Hebrew after the age of 10.

Procedure.--Each subject was tested for three hours on Hebrew characters and for two hours on Roman characters. In all instances the subject wrote down his own responses. Each stimulus consisted of eight letters arranged in two rows of four. Post exposure coded auditory cues of 200 or 1,000 Hz indicated the subject to report either the bottom row or the top row. The cue occurred either -50, 0, 50, 150, 350, or 750 msec after the 50 msec stimulus exposure. Each subject was paid for his participation.

Results and Discussion

The results of the experiment are shown in Figures 2 and 3. It is clear from Figure 2 that not only do the native Hebrew readers perform better than non-natives in the Hebrew alphabet, there is also much stronger evidence for loss of information from iconic memory. This result provides some support for the notion that the amount of experience interacts with the type of experience.

Figure 3 shows the results for both groups in the Roman alphabet. As that figure shows, it is difficult to differentiate the two groups in terms of their overall performance. This finding that performance is higher than found with the Hebrew alphabet probably is due to the greater simplicity of the Roman alphabet.

Implicit in these comparisons is the suggestion that the type of experience is more important than the amount of experience. The native Hebrew readers have had less experience with the Roman alphabet than the non-natives and yet do as well in the Roman alphabet.

In summary, the present results together with other data appear to be consistant with the following theoretical statements. First, experience in labeling improves performance by making the loading of short-term verbal easier. As experience increases, less time is required to retrieve the appropriate label and consequently more items can be put into short-term memory in a given time. Second, the order in which items are put into short-term memory is a function of the type of experience with the material. Finally, both of the above factors are involved in the amount of information which can be transferred out of iconic memory.

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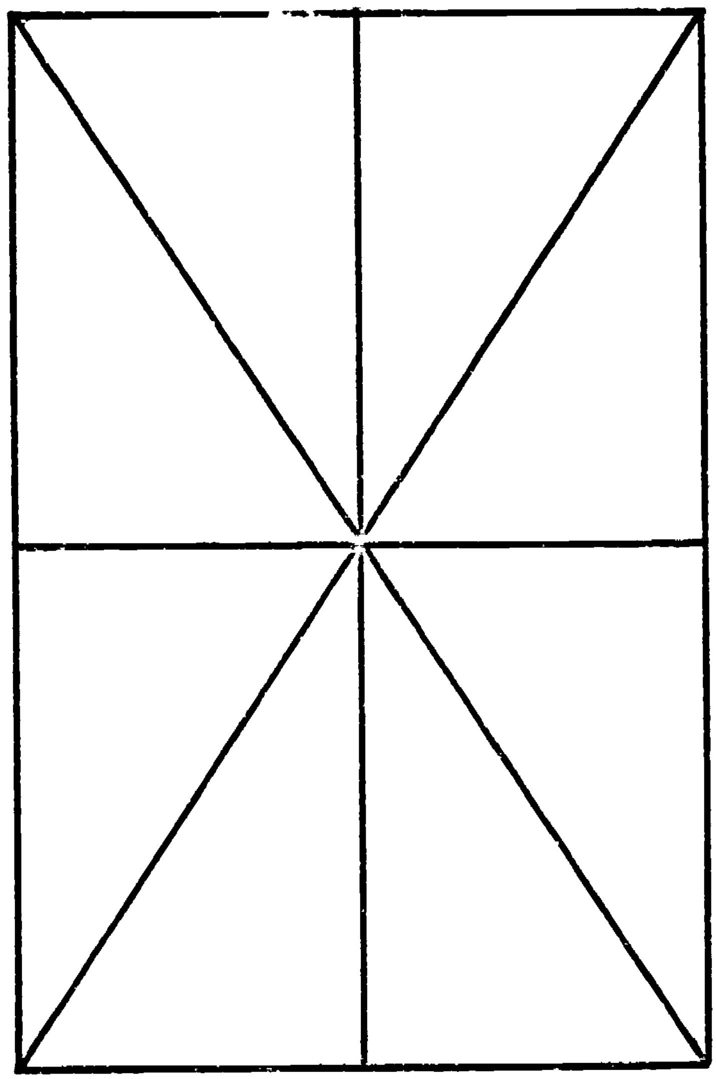
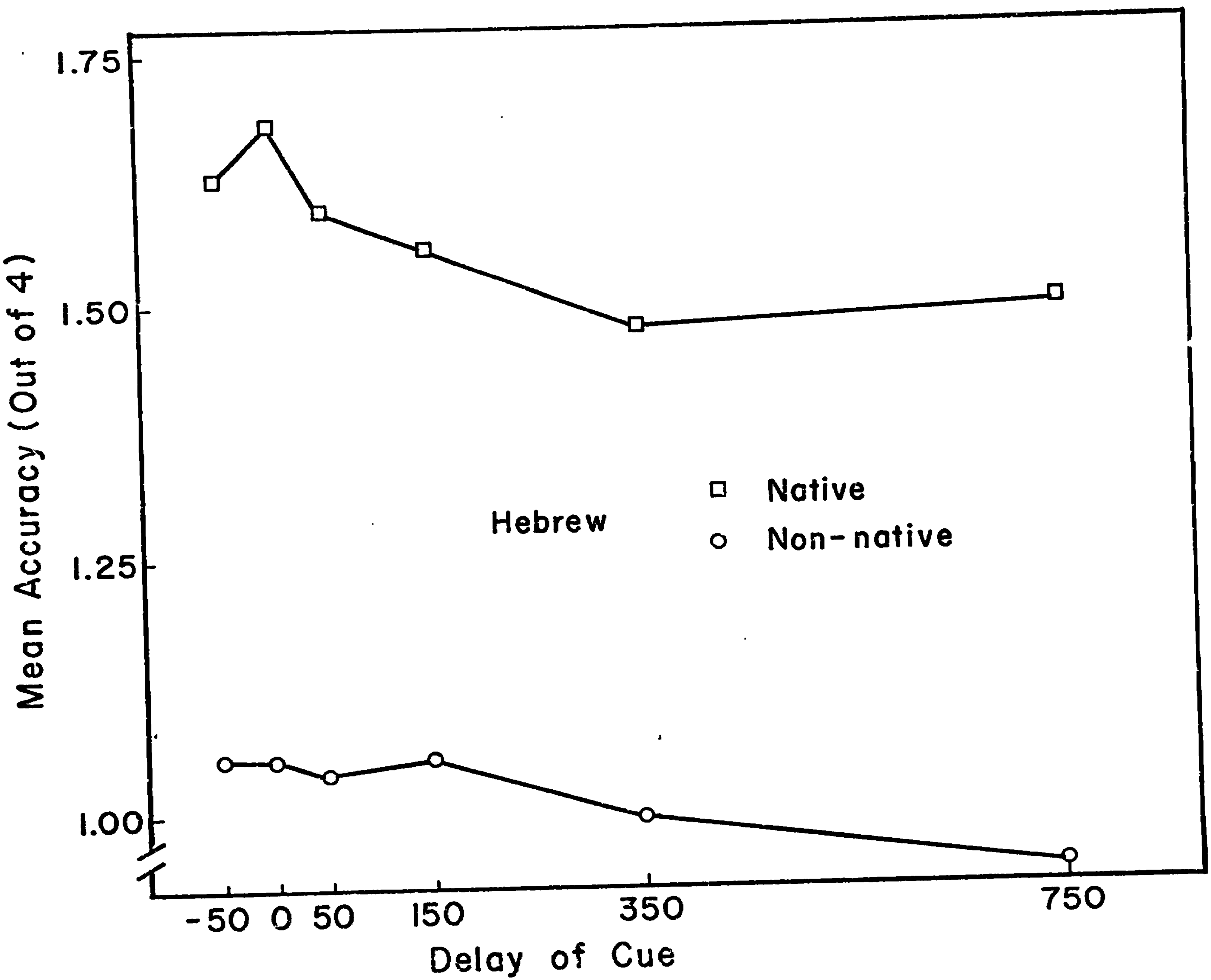
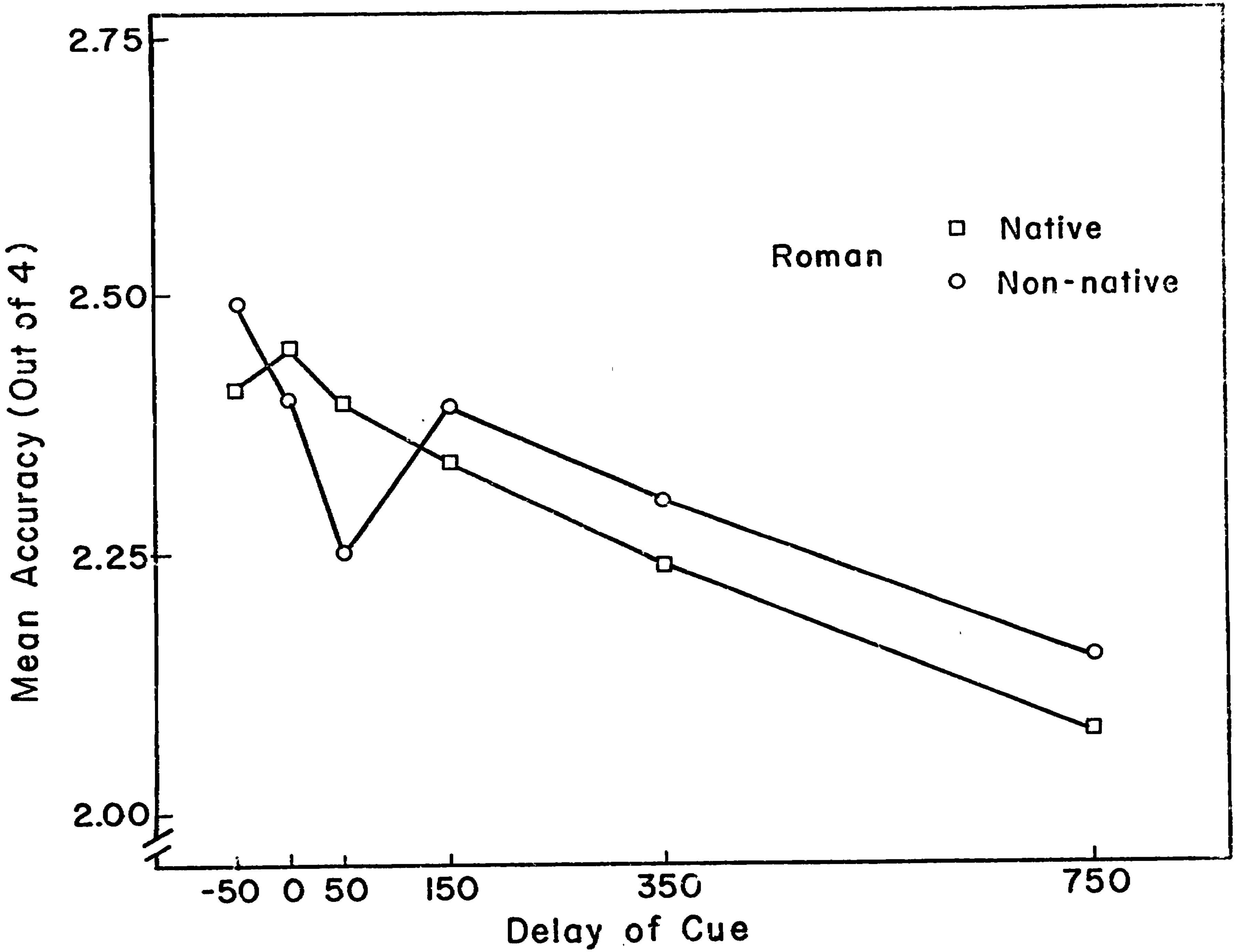
Figure Captions

Figure 1: The configuration from which lines were randomly selected to produce forms in Experiment I.

Figures 2 and 3: Mean accuracy of report as a function of delay of the auditory cue.




1.75
1.50
1.25
1.00
Mean Accuracy (Out of 4)
Hebrew
Native
Non-native
-50 0 50 150 350 750
Delay of Cue



2.75
2.50
2.25
2.00
Mean Accuracy (Out of 4)
Roman
Native
Non-native
-50 0 50 150 350 750
Delay of Cue